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DEMONSTRATION OF ICE PIGGING TECHNOLOGY TO REMOVE BIOFILMS IN WATER DISTRIBUTION SYSTEMS

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14. ABSTRACT Excessive buildup of biofilm and sediment in Department of Defense (DoD) water distribution systems can lead to loss of residual disinfectant as well as generation of elevated levels of disinfection byproducts such as nitrite/nitrate and trihalomethanes (THMs), which could trigger Safe Drinking Water Act (SDWA) violations. Common solution is implementation of extensive hydrant flushing programs to discard water that no longer has adequate residual disinfectant, and continue flushing until adequate residual is restored. This project demonstrates removal of biofilms and sediment buildup in drinking water distribution systems at Naval Air Station Lemoore, California, using a new water main cleaning technology known as ice pigging. Effective removal of biofilms could reduce the need for water system flushing, resulting in significant water saving.

Ice pigging uses an ice and water slurry that is introduced into the water mains, and gets propelled through pipes using the distribution system's own pressure to achieve cleaning and removal of loose materials on pipe walls with minimal impact on water system operation. The ice plug forms a compact durable mass to scrape pipe surfaces without the risk of permanently blocking choke points in the system. Unlike the conventional pig, the ice-water slurry is able to maneuver itself through pipes having different sizes, bends, valves, and fittings without risking system blockage or damages. The ice pigging waste is collected through downstream hydrants for disposal. Project team demonstrated the ice pigging technology at Naval Air Station Lemoore, California in May 2016. The demonstration cleaned 55,845 feet of pipes having diameters ranging from 6 to 16 inches. To evaluate the technology's performance, benefits, and costs, the project monitors hydrant flushing frequency and volumes, and system water quality, including bacterial analysis for pre- and post-pigging to validate improvement in system operations.

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LIST OF ACRONYMS

16S rRNA	Genome sequencing analysis
ACP	Asbestos cement pipe
AWWA	American Water Works Association
CI	Cast iron
DI	Ductile iron
DoD	Department of Defense
EO	Executive Order
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program Office
EXWC	Engineering and Expeditionary Warfare Center
GPM	Gallon per minute
HDPE	High-density polyethylene
HPC	Heterotrophic Plate Count
LF	Linear feet
MCL	Maximum Contaminant Level
NSF	National Sanitation Foundation
NASL	Naval Air Station, Lemoore
NAVFAC	Naval Facilities Engineering Command
NIST	National Institute of Standards and Technologies
OM&R	Operations, maintenance, and repair
PSI	Pounds per square inch
PVC	Polyvinyl Chloride
SDWA	Safe Drinking Water Act
SIOH	Supervision, inspection and overhead
SIR	Savings-to-investment ratio
TTHM	Total trihalomethane
UEM	Utility and Energy Management

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EXECUTIVE SUMMARY

A. INTRODUCTION

DoD water supply system is a critical infrastructure and essential to all DoD missions. All DoD facilities have water distribution systems to provide safe drinking water for personnel living or working on-base and total water consumption is estimated at about 90 billion gallons/year at all DoD facilities. Distribution system operations require proper cleaning of the water mains because distribution pipes are not sterile. As soon as finished water leaves a treatment plant and travels into the distribution system, the quality of the water begins to degrade due to time dependent transformations. Over time, sediments and debris that build up in water mains can cause pressure and flow problems. Complex microbiological, chemical, and physical interactions occur between water biofilms, debris, and pipe wall materials that can decay water quality.

Excessive buildup of biofilm and sediment in DoD water distribution systems can lead to the loss of residual disinfectant in the pipelines as well as the generation of elevated levels of disinfection byproducts, such as nitrite/nitrate and trihalomethanes (THMs), which could trigger Safe Drinking Water Act (SDWA) violations. Water system operators commonly address these water quality concerns by implementing extensive hydrant flushing programs to discard water which no longer has adequate residual disinfectant levels, and continue flushing until adequate residual is restored. An alternative to this practice is to address the problems directly by removing biofilm and sediments using a new technology known as ice pigging. This technology uses an ice and water slurry that is introduced into the pipe network, and gets propelled through pipes using the distribution system's own pressure to achieve cleaning and removal of loose materials on pipe walls with minimal impact on water system operation. The ice plug forms a compact durable mass which very effectively scrapes pipe surfaces without the risk of permanently blocking choke points in the system. Unlike conventional pipeline pigs, the ice-water slurry is able to maneuver itself through pipes having different sizes, bends, valves, and fittings without risking system blockage or damages. The ice pigging waste is collected through downstream hydrants for disposal.

Field demonstration was conducted at the Operations Area (OPS Area) of Naval Air Station, Lemoore, California in May 2016. The study was performed by the Naval Facilities Engineering Command (NAVFAC), Engineering and Expeditionary Warfare Center (EXWC) in collaboration with the US Army Engineer Research and Development Center (ERDC), SUEZ, and National Resources Consultants.

The project conducted ice pigging on 55,845 feet of water mains having diameters ranging from 8 to 16 inches. Project team performed pre- and post-ice pigging monitoring and sampling to collect data for technology evaluation and validation. Data collected include amounts of sediment removed, residual chlorine, water used for hydrant flushing, chlorine consumption, bacterial testing and bacterial community analysis.

B. OBJECTIVE

The objective of this project is to demonstrate the removal of biofilms and sediment buildup in drinking water distribution systems using a pipe cleaning technology known as ice pigging. Effective removal of biofilms will reduce the need for periodic water system flushing events, which waste significant quantities of water.

The main benefits of this technology stem from the water savings resulting from reduced flushing that is currently performed routinely to maintain water quality. Ice pigging technology is an innovative pigging technique that would be more readily acceptable to DoD utility and energy managers to implement into their routine Operation and Maintenance (O&M) protocols.

C. TECHNOLOGY DESCRIPTION

Ice pigging is a technology that combines the operational advantages of traditional flushing with the cleaning impact of soft pigging, with minimal interruption to water services during pigging. Ice Pigging overcomes operational limitations commonly found in traditional cleaning methods. A main feature of Ice Pigging is that it does not get stuck in the pipeline or appurtenances; if for some reasons the pig would get stuck, operators would allow the ice to melt and flush it out from the main. Pipe bends, changes in pipe diameters, or butterfly valves can all pose problems for swabbing or pigging, yet ice pigs can easily overcome these obstacles. To launch and receive traditional pigs, excavations have to be made to allow the installation of launch and reception stations. These can result in very costly and extensive interruptions to water system operations, and can require the installation of bypass pumping to provide water supply.

An ice pigging process includes the following major operations:

Ice Production

Ice is made on-site using the potable water from existing distribution system. To maintain the correct consistency of the ice pig, food grade table salt approved by the National Sanitation Foundation (NSF) is used as a freezing point depressant. The salt is dissolved in potable water obtained from installation's water supply to form brine. The current maximum batch capacity for ice slurry is 2,700 gallons.

The brine is prepared in a 316 stainless steel delivery tanker with hoses connected to ice machines that are mounted on a separate trailer (Figure E-1). The brine is fed into the ice machines which, in turn freeze the liquid and returns it to the delivery tanker. This cycle continues until the ice slurry is at certain consistency labeled as the ice fraction. Ice fraction measures the amount of ice crystals as a percentage of total volume. Ice fraction is related to the cooling capability of the slurry compared to pure ice (100%); this is known as the Calorimetric Value. Ice Pig operators use a simple French press coffee plunger (Figure E.2) to test the "ice fraction" (or the ice thickness) on site prior to pumping the slurry into the main. Typically, the thickest ice slurry is used on plastic and sound concrete lined pipes as well as asbestos cement pipes (ACP). But when older unlined cast iron pipes are cleaned, a thinner ice slurry is used that does not clean as aggressively to avoid pipe damage. The thinner ice slurry will not disturb the buildup of tuberculation which could damage the integrity of an old heavily corroded unlined cast iron pipe.

Figure E-1. Ice Production Setup Showing the Delivery Rig (left) and Ice Machines (right)

Figure E-2. French Press Method of Testing the Ice Fraction

Ice Delivery

Setup for ice delivery varies slightly for different applications. A typical setup for a potable water main is shown in Figure E-3. The delivery rig connects to the inlet hydrant or other suitable fitting (2" or greater tapping with valve control), and at the outlet, a Flow Analysis

System (FAS) is connected. The FAS measures and records the flow rate, pressure, conductivity, turbidity and water temperature as the water and ice are discharged. Once set up, the main is flushed briefly to note and record pre-flush readings. The main is then isolated by the owners' operators and the required amount of ice is pumped into the main. At the same time, the outlet hydrant is opened to create a flow and allow water to be displaced as the ice enters the main. With careful control between the inlet and outlet, the flows are balanced to allow slightly more ice into the main than the amount of water being displaced. This has the effect of the ice forming as a pig against a pressurized wall of water.

Once the required amount of ice is in the main, the delivery pump is turned off and the upstream valve is opened to allow the system flow and pressure to "push" the ice pig along the main toward the outlet hydrant. The flow rate is controlled by the outlet operator at this time. The line pressure is maintained above 20 psi to eliminate the need for the utility to issue a boil order. As the ice passes along the pipe, it removes and collects sediment, biofilm or debris that has accumulated around the circumference of the pipes. As the ice pig approaches the designated outlet, the conductivity reading will rise as the salty water of the melting pig arrives in front of the pig.

The monitoring equipment will show the water temperature falling and conductivity rising as the ice arrives. At this stage, the operator may collect samples of the ice at regular intervals for later analysis. The temperature and conductivity will return to pre-flush levels when all the ice and salty water has flushed out of the system and the flushing shall continue briefly to allow the turbidity levels to return to pre-flush levels or lower according to instructions from the owner. The main is then returned to normal service. No disinfection is necessary.

Disposal of the ice pig waste is typically through sanitary sewers; however, it can also be hauled away for disposal via a tanker for job sites that do not have access to sanitary sewers.

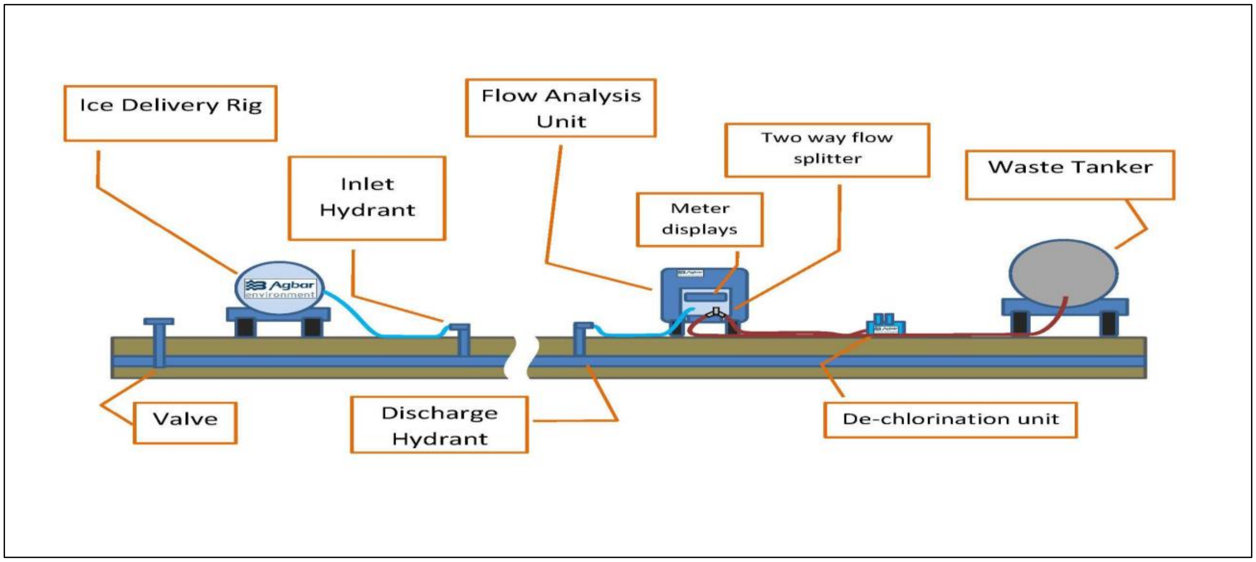

Figure E-3. Schematic Diagram of Ice Pigging Operation

D. PERFORANCE ASSESSMENT

Demonstration results showed significant improvement to the operation of the water system post-ice pigging. Sediments removed by ice pigging ranged from 8.3 to 81.8 lbs per mile of pipe cleaned whereas conventional hydraulic flushing did not remove any sediment. Residual chlorine did not change significantly before and after ice pigging and was steady at a level above 1.0 mg/L. Water used for hydraulic flushing was reduced from 5.5 million gallons per year before ice pigging to 2.3 million gallons per year post-ice pigging. Ice pigging can be finiancailly justifiable at water rate of $0.008/gallon or higher due to this water saving. Sodium hypochlorite consumption for re-chlorination was reduced by 465.1 gallons per year post-ice pigging. There was no TTHM violation after ice pigging, whereas four violations were recorded the year prior to ice pigging when only conventional hydraulic flushing was performed for system maintenance.

Results of the bacterial community analysis study in water distribution pipelines using 16S rRNA sequencing procedures showed that ice pigging removed entrenched biofilms and bacterial species highly resistant to the disinfectant, whereas conventional flushing only removed bacterial species closer to surface of biofilms in contact with water. Also, in pipelines with extreme levels of chlorine, highly resistant *bacilli* predominated, whereas, under less extreme conditions, proteobacteria formed the predominant species. Biofilms can exert chlorine demand and generate THMs, and hence the effective cleaning provided by ice pigging can help maintain distribution system water quality for a longer time horizon.

Table E-1 shows the comparison of conventional hydraulic flushing and ice pigging performance. Although the overall results are positive, they cannot all be attributed to ice pigging alone because the site has also implemented other improvement measures, such as the addition of a booster pump station to lower the water ages of parts of the distribution system, and a recirculation system to improve water circulation in the water storage tanks. It is a combination of the cleaning of water mains and the water age reduction measures that were undertaken that have resulted in the improvements.

Table E-1. Comparison of Conventional Flushing and Ice Pigging Performances.

Parameter	Conventional Hydraulic Flushing	Ice Pigging	Improvement
Sediments removed	0 lbs sediments/mile of pipe	8.3 to 81.8 lbs sediments/mile of pipe	Ice pigging removes sediments
Water used in hydrant flushing	5.5 million gallons per year	2.3 million gallons per year	3.2 million gallons annual reduction
Residual chlorine	Met minimum requirement	Met minimum requirement	No significant change
Chlorine for re-chlorination	694.7 gallons/year	229.6 gallons/year	465.1 gallons annual reduction
Annual TTHM violations	4 violations	0 violation	Avoided violations post-ice pigging

Biofilm Removal	Bacterial species close to the biofilm-water interface	Entrenched biofilms highly resistant to disinfectant	Remove bacteria close to pipe interior surface

E. COST ASSESSMENT

Table E-2 summarizes the cost elements associated with ice pigging performed in this demo.

Table E-2. Cost Model for Ice Pigging at NASL

Cost Element	Quantity		Unit Cost	Total ($)
Ice pigging contract cost	55,845	ft	3.22	180,036
Contract fee, 2.3%	1	LS	4,141	4,141
SIOH, 6%	1	LS	10,802	10,802
Total ice pigging cost				194,979

The main cost drivers associated with ice pigging are the size (such as pipe diameters and lengths) of the water distribution system to be pigged, and complexity of the system (such as availability of insertion and extraction ports for ice pigging).

The size of distribution system required to be pigged in terms of linear feet of pipe length, and pipe diameters determine the number of loads of ice needed for the project. Each load consists of 2,700 gallon of ice slurry and requires a whole day for production on-site. The higher the number of loads for a particular project, the lower the unit cost of ice pigging. For example, ice pigging projects at NBVC Port Hueneme and NASL required 3 and 12 loads of ice, respectively, corresponding to unit costs of $8.08 and $5.56 per gallon of ice.

Long water mains that do not have access for insertion and extraction ports would incur additional costs to install appropriate ports. It is very rare that this would be required.

The project team performed life-cycle cost analysis to compare life-cycle cost of ice pigging with conventional hydrant flushing. Cost analysis results show that ice pigging does not result in a net cost saving. Although the water saving is significant, it does not translate into a net cost saving due to the current low water rate of $0.004 per gallon. Sensitivity analysis showed that ice pigging could have cost benefit when water rate is $0.008 per gallon or higher. Ice pigging also has other intangible benefits such as proper maintenance of water distribution system, improved hydraulic capacity, and it also aids in water quality compliance that might offset the cost burden.

F. IMPLEMENTATION ISSUES

Ice pigging technology has been commercialized, and SUEZ is the only company that can perform ice pigging as the sole licensee of the technology. Implementation is typically achieved through standard contracts to procure ice pigging services.

Ice pigging is an effective water main cleaning technique that might help in improving the operation of DoD drinking water distribution system. Water systems may not need water main cleaning when routine conventional hydraulic flushing is sufficient to attain adequate disinfectant residuals within the water system as well as attaining compliance with SDWA water quality standards. Water main cleaning by ice pigging would be a good option to consider when water systems require aggressive hydrant flushing in order to comply with water quality standards. It could have a cost saving effect from reduced water wastage for flushing if the water rate is $0.008 per gallon or higher or if water rates are expected to escalate rapidly due to droughts. For water systems where free chlorine is used for disinfection, typical water quality issues arise from the loss of disinfectant residuals, and from violations of the TTHM MCL requirement. For water systems using chloramine as disinfectant, nitrification (elevated nitrate/nitrite levels and low disinfectant residual) is the main water quality issue. Water systems experiencing stagnant water issues should implement other measures to reduce water age first because water main cleaning will not increase water demand or cause the water to move faster to reduce water age.

The risk of damage to water pipes is very low since ice pigging uses water systems' own water pressure for pigging. A water distribution system planned for ice pigging should be in fair operating condition. Water mains meeting requirements for normal water distribution system operations are suitable for ice pigging.

Furthermore, based on lessons learned from this project, installations should consider the issues listed below when planning for ice pigging.

- Water service disruption could be very problematic for DoD facilities performing critical missions. It is difficult to communicate water stoppage schedules to all affected facilities. Project planning should include adequate coordination with affected facilities to work out acceptable water stoppage schedules. Ice pigging operations can be completed within three hours if preparation is adequate and there are no abnormal problems in the field affecting implementation. Thus, with proper coordination, water stoppage can be scheduled for early morning hours before normal business hours such that water service can be restored during business hours. It can also be scheduled during weekends to minimize impacts to facilities performing critical missions.

- Ice pigging requires support from the water distribution system operators to perform tasks such as operating valves for ice pigging operations, shutting off and turning on water supplies to affected facilities, coordinating with facility access, locating valves, etc. Planning should account for the availability of needed resources to support ice pigging.

- For instances where valves cannot be located due to inaccurate drawings, a metal detector is very helpful for locating valves and other appurtenances.

1.0 INTRODUCTION

This study was conducted by the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) in collaboration with the U.S. Army Engineer Research and Development Center (ERDC), SUEZ, and National Resources Consultants. Field demonstration of this project was conducted at the Naval Air Station, Lemoore (NASL) in CA. NASL was a good candidate for the validation and demonstration of this technology because like many Navy installations, the base suffered from persistent and recurring issues in maintaining adequate chlorine residual levels in their potable water supply. This is primarily due to the low flow velocities in piping that is oversized to meet the Department of Defense (DoD) fire flow requirements, a situation that is common on large military installations. By fully demonstrating the positive benefits of ice pigging at NASL, many other military installations will benefit from the documented results.

Effective removal of biofilms could reduce the need for water system flushing which wastes significant quantities of water. The main benefits of this technology are the improvements in water quality, water savings resulting from reduced flushing that is performed routinely to maintain water quality, reduced chlorine consumption, and reduced maintenance costs. Ice pigging technology is an innovative pigging technique that would be more readily acceptable to DoD utility and energy managers to implement into their regular Operation and Maintenance (O&M) protocols.

1.1 BACKGROUND

DoD water supply system is a critical infrastructure and essential to all DoD missions. All DoD facilities have water distribution systems to provide safe drinking water for personnel living or working on-base and total water consumption is estimated at about 90 billion gallons/year at all DoD facilities. Distribution system operations require proper cleaning of the water mains because distribution pipes are not sterile. As soon as finished water leaves a treatment plant and travels into the distribution system, the quality of the water begins to degrade due to time dependent transformations. Over time, sediments and debris that build up in water mains can cause pressure and flow problems. Complex microbiological, chemical, and physical interactions occur between water biofilms, debris, and pipe wall materials that can decay water quality. Water main cleaning is an effective and sustainable way to maintain water quality and extend water main service life.

1.1.1 CURRENT TECHNOLOGY STATE OF THE ART

Friedman et al (2012) have provided a comparative analysis of five water main cleaning techniques, and have ranked them based on the aggressiveness of each.

- Unidirectional Flushing (UDF): Distribution system pipes are flushed in a controlled and sequential manner. Flow direction and velocity are controlled through valve isolation to establish velocities of 6 feet per second (fps) or higher within each pipe segment. UDF is more effective than conventional flushing because scouring velocities can be intensified; thus entrained and some attached materials can be removed fro
- m the distribution system.

- Ice Pigging: Ice slurry is pumped into the water main and the ice "pig" is carried by upstream pressure to a downstream exit hydrant discharging into a sanitary sewer or collected in a truck for disposal. Ice is created on-site by special equipment using water from the distribution system. The ice slurry scours and entrains accumulated deposits as it moves downstream. NSF-graded salt is added to the ice to suppress the freezing point and slow the melting of ice. The ice slurry can be injected through hydrants without the need for excavation and can easily move through bends, diameter changes, and valves.

- Swabbing: Swabbing relies on the physical shearing action of a low-density, highly compressible foam cylinder or cube on the pipe wall. Swabs are larger than the inside diameter of the pipe, and are compressed during swabbing to increase frictional shear forces against the pipe wall thereby improving the removal of soft deposit and biofilm. Swabs are forced through hydrants or launching stations using a pumper truck.

- Pigging: A pig is a rigid, bullet-shaped object that is pushed along a predetermined pipe route, and it scours the sides of a main as it passes through. A pumper truck is used to force the pig into the main. Distribution system water is used to propel the pig and force it to a predetermined recovery point in the system, where the used pig and material removed from the pipe walls are retrieved. Because pigging is more aggressive, pipe relining may be required.

- Mechanical Cleaning: Mechanical cleaning can vary in forms but all have the same basic concept. A scraping device is introduced into a pipe segment and pushed or pulled mechanically until the pipe walls are clean. This method can clean a pipe's interior down to bare material and should always be followed by pipe lining to prevent interior corrosion of the pipes after cleaning.

The cleaning techniques of swabbing, pigging, and mechanical cleaning are quite aggressive and difficult to perform. In many cases, the use of launching stations involving the excavation and cutting of pipes may be required. These techniques could damage valves and pipe walls and are not suited for DoD distribution systems, which are typically old. Table 1 presents a comparison of water main cleaning technologies currently available.

Table 1. Comparison of Current Water Main Cleaning Technologies

Comparative Cost Approximation
It's difficult to develop "apples-to-apples" cost comparison. Actual costs are site-specific and subject to numerous different local cost variables

Technique	Objective	Estimated Total Costs – Capital and O&M, ($/mi)*	Estimated Total Costs – O&M and Capital, ($/LF)*	Estimated frequency (years)
Conventional flushing	Bulk water, loose deposits	$236	$0.04	1-7 days
UDF	Bulk water, loose deposits, cohesive deposits	$5,000 first time $3,000 repeat	0.95	0.5-3
Ice Pigging	loose deposits, cohesive deposits, adhered deposits, and hard scale	$9,000-$29,000	1.7-5.5	3-7
Swabbing		30,000-48,000	5.7-9.1	3-7
Pigging**		85,000-111,000	16.1-21	>=10
Mechanical Cleaning***		422,400-517,440	80-98	>=20

Adapted from work conducted by Confluent Engineering Group and Kenney/Jenks Consulting for two West Coast utilities. Cost information for ice pigging provided by Utility Service Group.
*Assumes labor rate of $100/hr. Cost significantly affected by the number of people per crew, number of loops per mile, etc.
**Assumes no rehabilitation or major system modifications because need is site-specific
***Assumes rehabilitation and system modifications required for implementation.

1.2 OBJECTIVE OF THE DEMONSTRATION

The main objective was to demonstrate that ice pigging can reduce the amount of water needed for routine conventional hydraulic flushing while meeting water quality standards, by removing sediment and biofilms in water mains that contribute to SDWA violations. The project intended to demonstrate the effectiveness of ice pigging in removing the accumulated sediments and biofilms from water mains. The cleaning effectiveness was assessed in the short-term by quantifying the amounts of deposits removed during ice-pigging, and analyzing for the chemical and biological constituents of the removed materials. Long term assessments include improvement in the maintenance of chlorine residual, reduction in water volume needed for conventional hydraulic flushing, and compliance with water quality requirements.

1.1 REGULATORY DRIVERS

There are several drivers pushing the desire to reduce water consumption and allowing the new Ice Pigging technology to be a viable alternative to the traditional flushing that is currently being conducted at DoD facilities.

1.3.1 EXECUTIVE ORDERS

Executive Order (EO) 13514 of October 5, 2009. expands upon the energy reduction and environmental performance requirements of EO 13423. It directs Federal agencies to improve water use efficiency and management of water resources by: (i) reducing potable water consumption intensity by 2 percent annually through fiscal year 2020, or 26 percent by the end of fiscal year 2020, relative to a baseline of the agency's water consumption of 111 billion gallons in fiscal year 2007; and (ii) consistent with State law, identifying, promoting, and implementing water reuse strategies that reduce potable water consumption.

The need for water conservation is also addressed in the "Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (2006): Indoor Water". This MOU requires employment of strategies that in aggregate will result in use of a minimum of 20 percent less potable water than the indoor water use baseline calculated for the building. This is to be done after meeting the Energy Policy Act of 1992 fixture performance requirements. The water conservation goals of the above two EOs can be achieved more meaningfully if the vast amount of water that is flushed and lost from DoD distribution systems is reduced. If this amount is reduced by 26%, the goals of the mandated reduction of potable water consumption will be met.

1.3.2 REGULATIONS

- Long Term 2 Enhanced Surface Water Treatment Rule (LT2 rule): The LT2 rule was adopted to improve drinking water quality and provide additional protection from disease-causing microorganisms and contaminants that can form during drinking water treatment and distribution. Chlorine residual levels must be at least 0.2 mg/L at the entry to the distribution system, and positive in the distribution system. Pathogens, such as Giardia and Cryptosporidium, are often found in waters from surface sources, and can cause gastrointestinal illness (e.g., diarrhea, vomiting, and cramps) and other health risks. In many cases, this water needs to be disinfected through the use of agents such as ozone, chlorine dioxide or UV irradiation to inactivate (or kill) microbial pathogens during water treatment.

- Total Coliform Rule (TCR): The purpose of the 1989 TCR is to protect public health by ensuring the integrity of the drinking water distribution system and monitoring for the presence of microbial contamination. For drinking water, total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system. The absence of total coliforms in the distribution system minimizes the likelihood that fecal pathogens are present. Thus, total coliforms are used to determine the vulnerability of a system to fecal contamination. On February 13, 2013, EPA revised the 1989 TCR which takes effect on 1 April 2016 for all public water systems. The revised Total Coliform Rule (RTCR) upholds the purpose of the 1989 TCR to protect public health by ensuring the integrity of the drinking water distribution system and monitoring for the presence of microbial contamination. It requires public water systems (PWSs) to meet a legal limit for E. coli, as demonstrated by required monitoring. Also, the RTCR specifies the frequency and timing of required microbial testing based on population served, public water system type and source water type: ground water or surface water.

- Stage 2 Disinfection and Disinfectant-By-Product (DBP) rule: The Stage 2 DBP rule was developed to improve drinking water quality and provide additional protection from disinfection byproducts. This rule requires water systems to perform monitoring and determine compliance with the disinfectant by-products (such as TTHMs) maximum contaminant levels (MCLs) by calculating the running annual average of samples for each monitoring location in the distribution system.

2.0 TECHNOLOGY DESCRIPTION

Ice Pigging is a new and innovative water main cleaning technique that is promising for reducing water consumption and maintaining water quality at DoD facilities. Developed at the University of Bristol, UK, and patented in 2005, ice pigging was introduced to the US market in 2012 by the Utility Service Group (USG) company (acquired by SUEZ later). Although ice pigging is relatively new in the US, it has been utilized widely and has earned international accolades including the Innovation Prize by Water UK and the IWA Innovation Award in 2010.

2.1 TECHNOLOGY OVERVIEW

Ice pigging is a technology that combines the operational advantages of traditional flushing with the cleaning impact of soft pigging, with minimal interruption to water services during pigging. Ice Pigging overcomes operational limitations commonly found in traditional cleaning methods. A main feature of Ice Pigging is that it does not get stuck in the pipeline or appurtenances; if for some reasons the pig would get stuck, operators would allow the ice to melt and flush it out from the main. Pipe bends, changes in pipe diameters, or butterfly valves can all pose problems for swabbing or pigging, yet ice pigs can easily overcome these obstacles. To launch and receive traditional pigs, excavations have to be made to allow the installation of launch and reception stations. These can result in very costly and extensive interruptions to water system operations, and can require the installation of bypass pumping to provide water supply.

An ice pigging process includes the following major operations:

<u>Ice Production</u>

Ice is made on-site using the potable water from existing distribution system. To maintain the correct consistency of the ice pig, food grade table salt approved by the National Sanitation Foundation (NSF) is used as a freezing point depressant. The salt is dissolved in potable water obtained from installation's water supply to form brine. The current maximum batch capacity for ice slurry is 2,700 gallons.

The brine is prepared in a 316 stainless steel delivery tanker with hoses connected to ice machines that are mounted on a separate trailer (Figure 1). The brine is fed into the ice machines which, in turn freeze the liquid and returns it to the delivery tanker. This cycle continues until the ice slurry is at thickness known as the ice fraction. Ice fraction measures the amount of ice crystals as a percentage of total volume. Ice fraction is related to the cooling capability of the slurry compared to pure ice (100%); this is known as the Calorimetric Value. Ice Pig operators use a simple French press coffee plunger (Figure 2) to test the "ice fraction" (or the ice thickness) on site prior to pumping the slurry into the main. Typically, the thickest ice slurry is used on plastic and sound concrete lined pipes as well as asbestos cement pipes (ACP). But when older unlined cast iron pipes are cleaned, a thinner ice slurry is used that does not clean as aggressively to avoid pipe damage. The thinner ice slurry will not disturb the buildup of tuberculation which could damage the integrity of an old heavily corroded unlined cast iron pipe.

Figure 1. Ice Production Setup Showing the Delivery Rig (left) and Ice Machines (right)

Figure 2. French Press Method of Testing the Ice Fraction

<u>Ice Delivery</u>

Setup for ice delivery varies slightly for different applications. A typical setup for a potable water main is shown in Figure 3. The delivery rig connects to the inlet hydrant or other suitable fitting (2" or greater tapping with valve control), and at the outlet, a Flow Analysis System

(FAS) is connected. The FAS measures and records the flow rate, pressure, conductivity, turbidity and water temperature as the water and ice are discharged. Once set up, the main is flushed briefly to note and record pre-flush readings. The main is then isolated by the owners' operators and the required amount of ice is pumped into the main. At the same time, the outlet hydrant is opened to create a flow and allow water to be displaced as the ice enters the main. With careful control between the inlet and outlet, the flows are balanced to allow slightly more ice into the main than the amount of water being displaced. This has the effect of the ice forming as a pig against a pressurized wall of water.

Once the required amount of ice is in the main, the delivery pump is turned off and the upstream valve is opened to allow the system flow and pressure to "push" the ice pig along the main toward the outlet hydrant. The flow rate is controlled by the outlet operator at this time. The line pressure is maintained above 20 psi to eliminate the need for the utility to issue a boil order. As the ice passes along the pipe, it removes and collects sediment, biofilm or debris that has accumulated around the circumference of the pipes. As the ice pig approaches the designated outlet, the conductivity reading will rise as the salty water of the melting pig arrives in front of the pig.

The monitoring equipment will show the water temperature falling and conductivity rising as the ice arrives. At this stage, the operator may collect samples of the ice at regular intervals for later analysis. The temperature and conductivity will return to pre-flush levels when all the ice and salty water has flushed out of the system and the flushing shall continue briefly to allow the turbidity levels to return to pre-flush levels or lower according to instructions from the owner. The main is then returned to normal service. No disinfection is necessary.

Disposal of the ice pig waste is typically through sanitary sewers; however, it can also be hauled away for disposal via a tanker for job sites that do not have access to sanitary sewers.

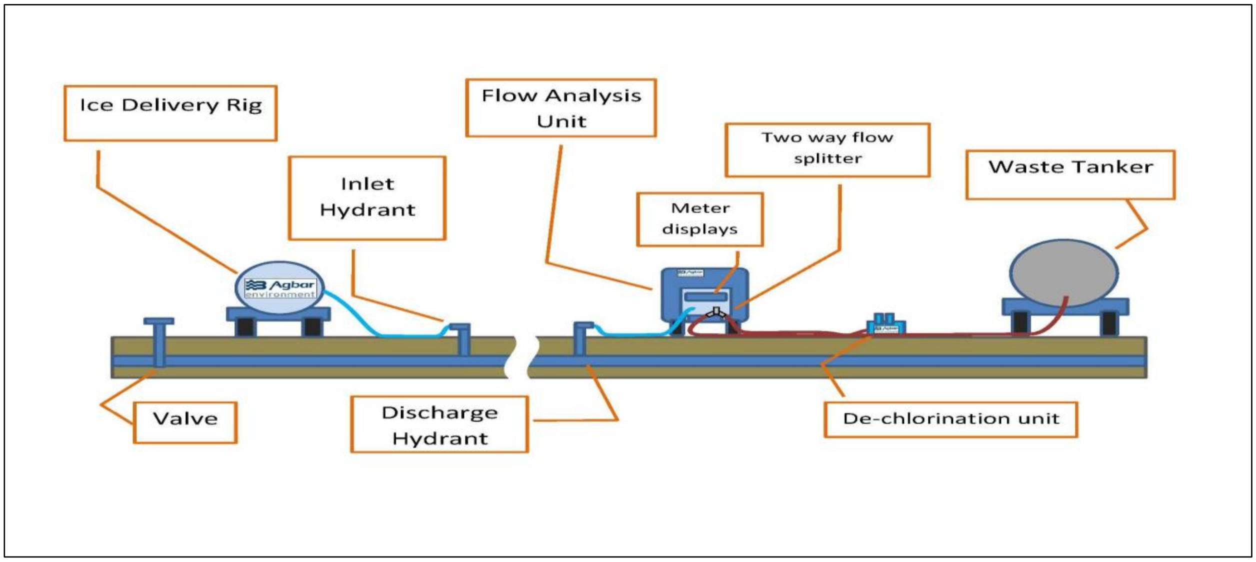

Figure 3. Schematic Diagram of Ice Pigging Operation

2.2 TECHNOLOGY DEVELOPMENT

Ice Pigging technology was developed at the University of Bristol, UK, and patented in 2005. Ice pigging was introduced to the US market in 2012 by the Utility Service Group (USG) company (acquired by SUEZ later). Although ice pigging is relatively new in the US, it has been utilized widely and earned international accolades including the Innovation Prize by Water UK and the IWA Innovation Award in 2010.

2.0 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Advantages and limitation of Ice Pigging technology over other water main cleaning techniques are listed in Table 2.

<u>Potential Barriers to Acceptance</u>:

- We anticipate that potential barriers to acceptance to be minimal.

Table 2. Advantages and Disadvantages of Various Water Main Cleaning Technique.

Ice Pigging	Conventional Hydraulic Flushing	Unidirectional Flushing	Swabbing, Pigging, Mechanical Cleaning
Uses less water.	Uses more water than ice pigging.	Uses more water than ice pigging.	Uses less water than ice pigging.
More effective cleaning due to higher scouring forces than UDF.	Least effective cleaning due to lowest scouring forces.	Higher scouring forces than conventional flushing.	Highest scouring forces.
Less likely to damage water main system.	Less likely to damage water main system.	Less likely to damage water main system.	High risk of damaging water main system.
Less disruptive to facility operations.	Least disruptive to facility operations.	Somewhat disruptive to facility operations.	More disruptive to facility operations.
Water lines do not require post disinfection.	Water lines do not require post disinfection.	Water lines do not require post disinfection.	Water lines require post disinfection.
Cost per linear foot is higher than UDF, lower than swabbing and mechanical cleaning.	Least cost per linear foot.	Second least cost per linear foot.	Highest cost per linear foot.
Installation costs are less than swabbing and mechanical cleaning, higher than conventional flushing and UDF.	Least installation costs.	Higher installation costs compared to conventional hydraulic flushing, but lower than ice pigging.	High installation costs.
Requires less frequent cleaning than UDF and likely more than swabbing and mechanical cleaning.	Requires most frequent cleaning.	Requires less frequent cleaning than conventional hydraulic flushing.	Requires the least frequent cleaning.
Effective for pipe diameter up to 24 inches in diameter.	Not effective for pipe diameter >8 inches.	Not effective for pipe diameter >16 inches.	No limitation on pipe sizes, >16 inch may need non-standard equipment.

3.0 PERFORMANCE OBJECTIVES

The performance objectives of this demonstration will be validated through baseline monitoring prior to ice pigging, sampling and analysis during ice pigging operations, and post-ice pigging monitoring. Monitoring will be performed using appropriate on-line monitors, collecting grab samples for laboratory analyses, and examination of operational log books and historical monitoring records.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

Table 3 summarizes the quantitative and qualitative performance objectives for this demonstration and their corresponding success criteria for assessing the achievement of the performance goals.

Table 3. Performance Objectives for Ice Pigging Demonstration

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Reduction of water used in flushing operations	Water consumption in gallons/year	Metered water consumption from conventional flushing.	Post-pigging reduction of >35% in water used for hydrant flushing relative to the measured baseline water consumption for flushing	Met
Cleaning effectiveness	Amount of sediments in lbs removed during ice pigging, and chemical and biological characteristics	Samples of ice pigs tested for TSS (mg/L), bacteria and bacterial community profile. Calculate amount of sediments removed in lbs sediment/ft^2 of pipe	Sediments removal >50% of those removed by current flushing program Positive biological tests will confirm biofilm removal	Met Met
Residual chlorine	Free chlorine concentrations (mg/L)	Pre- and post-ice pigging chlorine monitoring	Chlorine > 0.2 mg/L and average chlorine levels > baseline chlorine levels	N/A
TTHM Compliance	TTHM concentrations (ug/L)	Lab analysis EPA 524.2	Post ice-pigging TTHM concentrations <80 ppb for one year	Met

Turbidity	Turbidity measurement in NTU	Pre- and post-ice pigging on-line turbidity meter readings in NTU	Post ice-pigging reduction in turbidity >15% relative to baseline measurements for one year	Not Met
Chlorine consumption rate	Chlorine consumption rate in the OPS Area (lbs chlorine per million gallons water per day)	Amount of chlorine (liquid sodium hypochlorite) used in lbs/day, water production rates in million gallons per day	Chlorine consumption rate post-ice pigging is 15% less than baseline chlorine consumption rate	Met
System Economics	System return on investment (SIR)	Value of water, labor, and water treatment chemical saved/cost of ice pigging operation	SIR> 1.0	Not Met
Impact to water system and facility operations	Level of impact to water system and facility operations	Water system down time, damages to valves	<4 hours of water down time to critical facilities, zero valve damages from the ice pigging process	Met
Qualitative Performance Objectives				
User Satisfaction of ice pigging operations	No system modification required to use the process for entire pipe system	User survey	No modifications are required and the system could be satisfactorily ice pigged	Met
Consumer satisfaction	Consumer complaints regarding water quality	Number of complaints received pre- and post-ice pigging from operation log	Number of complaints post-ice pigging < complaints from pre-ice pigging	N/A

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

3.2.1 Reduction of Water Used in Hydrant Flushing

Name and Definition: Reduction of water used in flushing operations, which will equate to a reduction of potable water used in hydrant flushing after ice pigging.

Purpose: To evaluate water use reduction, if any, resulting from water main cleaning by ice pigging.

Metric: Water used in hydrant flushing within the OPS Area in gallons per year.

Data: Meter readings of the automatic flushing devices operated in the OPS Area. If meter readings are not available, flush schedule of the automatic flushing devices is used to calculate monthly water volumes used in hydrant flushing.

Analytical Methodology: Comparison of total water used in hydrant flushing before and after ice pigging. Also plot the hydrant flushing activities vs. time before and after ice pigging using scatter plots and histograms.

Success Criteria: More than 35% reduction by volume of water used for hydrant flushing after ice pigging operations.

Results: Water reduction was 55.6%. Volume of water used for hydrant flushing reduced from 5.36 pre-ice pigging to 2.38 million gallons per year after ice pigging.

3.2.2 Cleaning Effectiveness

Name and Definition: Cleaning effectiveness of ice pigging technology.

Purpose: Evaluate effectiveness of ice pigging technology to clean water main.

Metric: Amount of sediments removed from water mains in pounds per linear foot of pipe for particular pipe diameters during ice pigging and baseline flushing operations. Chemical and biological properties of the sediments removed.

Data: Grab samples from baseline flushing and from ice pigging runs tested for parameters listed in Table 4.

Table 4. Routine Samples during Ice Pigging Runs and Baseline Flushing

Test Parameters	Test Method	Sampling Interval
Total Suspended Solids (TSS)	EPA 160.2	Every 30 seconds during ice discharge for each run For baseline flushing, every 30 seconds the first 5 minutes, every 5
pH	EPA 9040	
Total Iron	EPA 6010	
Total Manganese	EPA 6010	
Chlorine Demand	SM2350B	
Total Phosphate	EPA 365.3	
Total Organic Carbon (TOC)	SM 5310C	
Heterotrophic Plate Count (HPC)	SM9215B	
Total Coliform	SM9223B	
Iron Reducing Bacteria	ASTM D932 - 15	

Sulfate Reducing Bacteria	ASTM D4412 - 15	minutes thereafter from 5-30 minutes

Collect additional baseline and ice pigging grab samples for bacterial community analysis through 16S rRNA gene sequencing to obtain information on predominant bacteria in the biofilms. Table 5 lists the schedule and frequency of bacterial community analysis sampling.

Table 5. Additional Bacterial Sampling

Ice Pigging Run	Sampling Interval	Constituents
Day 4 (Reeves 1), Hangars 1, 3 and 4	3 to 4 minutes before ice arrival, and 30s, 60s, 120s, 240s after ice arrival	Bacterial community analysis through 16S rRNA gene sequencing
Day 6 (Reeves 2), Hangars 3 and 5		
Day 7 (Ordnance Circle), WPNS Area		
Day 10 (Aircraft park 1)		
Day 12 (Hangar 2)		

Analytical Methodology: Analytical tests were performed in accordance with the standard test methods listed in Tables 4 and 5.

Success Criteria: Average sediments removal is 50% greater than that removed by the baseline flushing operation. Positive biological test results will confirm biofilm removal.

Results: Average sediments removed by ice pigging was 27.6 lbs per mile for pipe diameters of 8 to 16 inches. Baseline flushing did not remove any sediment. Bacterial community analysis confirmed that ice pigging removed entrenched biofilms and species highly resistant to disinfectants and colonize asbestos cement pipes, whereas conventional flushing removed surface bacteria only, species closer to the surface of biofilm.

3.2.3 Residual Chlorine

Name and Definition: Residual chlorine. Ability to meet the requirements for maintaining detectable chlorine concentrations in water distribution system.

Purpose: Evaluate improvement to the maintenance of residual chlorine concentrations after ice pigging.

Metric: Free chlorine concentrations in mg/L.

Data: Grab samples and online monitoring data for residual chlorine.

Analytical Methodology: Grab samples will be analyzed using EPA-approved free chlorine DPD (N, N-diethyl-p-phenylenediamine) Colorimetric Method. Online chlorine analyzer uses a polarographic membrane sensor to measure free chlorine.

Success Criteria: Chlorine concentrations remain above the allowable minimum of 0.2 mg/L and average chlorine levels remain above levels observed prior to pigging operation.

Results: The chlorine residuals for pre- and post-ice pigging were both above the minimum 0.2 mg/L level. However, the result for this metric is reported as "not applicable" in Table 3 as it was not possible to separate the influence of the newly installed recirculation system from that of the ice pigging operation.

Chlorine residual tends to decay to less than required levels in the far end of a distribution system where water is more stagnant. Conventional hydraulic flushing is typically performed to restore residuals in the dead-end areas by replacing old water with fresh water. If the pipes are clean and water age is not too high, residual should be slightly lower in the dead-end areas with normal flushing. If water is more stagnant and pipes are not clean, residual would decay faster due to higher chlorine demand and would require more aggressive flushing to maintain the residual above the minimum required level. Thus, residual is impacted by water age, flushing frequency and volume, and biofilms on the pipe walls.

Installation of a recirculation system by NAS Lemoore in Dec 2015 makes the determination of the impact of ice pigging difficult. Residual chlorine post-ice pigging is similar to that of the baseline and both are way above 0.3 mg/L. Since we started monitoring residual in January 2016, the baseline residual reflects the conditions with the recirculation system. The data show that adequate residual was maintained during the period after installation of the recirculation system and prior to ice pigging. After ice pigging, adequate residual was also maintained, except for a brief period when the recirculation system was off.

The demonstration shows that ice pigging by itself cannot maintain adequate residual if water age is high. It also shows that residual is good when both water mains have been cleaned by ice pigging and water age is under control. It would be interesting to see if satisfactory levels of chlorine residual are maintained when only water age is reduced (by the recirculation system) but the pipes are not cleaned. Unfortunately, we do not have the data to show that effect due to the timing of the demonstration.

3.2.4 TTHM Compliance

Name and Definition: TTHM compliance. Water in distribution system satisfies the TTHM maximum contaminant level (MCL) requirement.

Purpose: Evaluate TTHM compliance after ice pigging.

Metric: TTHM concentrations in micrograms per litter (µg/L) before and after ice pigging.

Data: Grab samples at the compliance sampling points within OPS Area. tested for TTHM using EPA 524.2 Method.

Analytical Methodology: Grab samples are analyzed for TTHM using EPA 524.2 Method.

Success Criteria: Post-ice pigging TTHM concentrations are less than 80 µg/L.

Results: TTHM concentrations the year prior to ice pigging exceeded the MCL of 80 ug/L four times. After ice pigging, there was no exceedance.

3.2.5 Turbidity

Name and Definition: Turbidity. Indicates the presence of colloidal particles in water.

Purpose: Evaluate cleanliness of pipes after ice pigging. As sediments are removed, fewer particles will be present in the water resulting in less turbid water.

Metric: Turbidity measurements in NTU.

Data: Online turbidity monitoring data.

Analytical Methodology: Online turbidity monitoring system using light-scattering method.

Success Criteria: After ice pigging, average turbidity in water distribution system is reduced by 15% or more.

Results: Turbidity results did not meet the performance objective of 15% reduction from the baseline level. However, this is mainly due to the low turbidity values pre- and post-ice pigging (less than 0.3 NTU), and the difficulty of measuring changes at this low level. The daily average turbidity data show that post ice pigging turbidity did not change significantly from the baseline. The trends in both cases are similar, with turbidity values less than 0.1 NTU during Winter, and steadily climbing in Spring towards 0.3 NTU. During period from July to September 2016, turbidity was higher. This might be due to water being stirred up when recirculation was turned back on in July. Turbidity was below 0.3 NTU for the most part, which is quite low. Although sediments were present on pipe walls prior to ice pigging, turbidity was low because no suspended solids were released into the water.

3.2.6 Chlorine Consumption Rate

Name and Definition: Chlorine consumption rate. Amount of chlorine disinfectant used in the OPS Area for water disinfection.

Purpose: Evaluate reduction in chlorine consumption in the OPS area after ice pigging.

Metric: Chlorine (liquid sodium hypochlorite) consumption rate in the OPS Area in pounds of chlorine per million gallons of water.

Data: Amount of chlorine (liquid sodium hypochlorite) used in pounds per day, water pumped to the OPS Area in million gallons per day.

Analytical Methodology: Tabulate operational data on chlorine consumption at the chlorine booster station in Building 50 and water production data.

Success Criteria: After ice pigging, chlorine consumption rate is 15% less than the baseline consumption rate.

Results: Water entering the OPS Area is pre-chlorinated and stored in two 60,000-gallon tanks. The water is re-chlorinated prior to entering the distribution system when residuals in the tanks are low. Chlorine consumption rate for the re-chlorination is determined mainly by the chlorine demand at the point of entry and is not impacted by ice pigging downstream. Thus, chlorine consumption rate is not a good indicator of the ice pigging performance. Although the demonstration shows that chlorine consumption rate was reduced more than 15% post-ice pigging, the reduction was attributed to the installation of a recirculation system in the OPS Area storage tanks after ice pigging. The installed system improves mixing in the tanks that eliminates or reduces the loss of residual due to water stagnation in the tanks. When residuals in the tanks are adequate, it is not needed to boost the chlorine when pumping into the distribution system.

3.2.7 System Economics

Name and Definition: System Economics. Estimated cost savings of ice pigging over current practice.

Purpose: Determine if ice pigging is more cost effective than the current practice of conventional flushing.

Metric: Costs of equipment, materials, and labor to perform ice pigging. Costs of water, labor, and materials used in current flushing practices.

Data: The SIR will be determined by capturing direct and indirect cost data for ice pigging and current practices.

Analytical Methodology: The National Institute of Standards and Technology (NIST) Building Life Cycle Cost Program will be used to evaluate the cost savings and SIR. Published discount rate will be used for life-cycle cost calculations.

Success Criteria: SIR > 1.0.

Results: Ice pigging would not result in a net cost saving (SIR = 0.5) under the current low water rate of $0.004/gal. However, it could generate cost savings if water rate is $0.008/gal or higher, due to the significant water savings from reduced flushing operations.

3.2.8 Impact to Water System and Facility Operations

Name and Definition: Impact of ice pigging operations on water distribution system and facility operations.

Metric: Level of impact to water distribution system and facility operations when ice pigging is performed.

Data: Water service downtime to critical facilities during ice pigging operation. Damages to valve and pipes resulting from ice pigging.

Analytical Methodology: Assess damage to valves by visual inspection and feedback from water system operators. Damage to pipes can be detected by pressure readings and deterioration of water quality. Water service stoppage is recorded in daily production reports during ice pigging.

Success Criteria: Less than four hours of water service downtime for critical facilities per pigging event. No damages to valves and pipes were observed.

Results: Water service downtime for critical facilities was less than 3 hours. No damages to valves or pipes were observed during all ice pigging runs.

3.2.9 User Satisfaction

Name and Definition: End user satisfaction on ice pigging operation.

Metric: Feedback from NASL personnel regarding success of ice pigging process.

Data: Survey feedback on demonstration.

Analytical Methodology: Conduct post demonstration survey of NASL personnel to acquire their feedback.

Success Criteria: Positive feedback from end user.

Results: Informal data from the end user operations and management personnel indicate positive feelings and satisfaction with respect to the deployment and operation of the ice pigging demonstration. End user is satisfied with the amount of sediment removed from the pipelines.

3.2.10 Consumer Satisfaction

Name and Definition: Consumer satisfaction regarding water quality.

Metric: Consumer complaints regarding water quality, such as color, taste, and odor.

Data: Number of consumer complaints regarding water quality and aesthetic properties before and after ice pigging.

Analytical Methodology: Collect and tabulate consumer complaints from log books.

Success Criteria: Number of consumer complaints after ice pigging is less than the number of complaints before ice pigging.

Results: Consumer complaints are more likely to be received when the supplied water has taste and/or odor problems, or if the water is discolored from sediments or corrosion products. Since there are no CI or steel pipes in the system, there is less likelihood of color due to oxides or sediment being released in significant quantities to elicit consumer complaints. TTHM violations are less likely to elicit responses from consumers due to the lack of sensory cues. Plant records indicate there were no complaints prior to and post ice pigging.

4.0 FACILITY/SITE DESCRIPTION

NASL was chosen as the site for the ice pigging demonstration. NASL was commissioned in 1961 and most of the water utility infrastructure was installed at that time. The main pump station in Building 50 (OPS area pump station building) has undergone an upgrade. Improvements over the years have included construction of new facilities, the addition of loops to the water distribution system, installation of hydrant flushers for draining or decreasing the water age in select areas. Based on discussions with NASL personnel, it is evident that very little water system maintenance has been performed in the past on the water distribution system infrastructure other than routine repairs.

4.0 FACILITY/SITE LOCATION AND OPERATIONS

NASL is located on Highway 198 in between Interstate 5 and Highway 41, near the city of Lemoore, California. The base is located in the rich agricultural lands of the San Joaquin Valley in a semi-arid climate region. NASL is divided into two separate areas, the Administration Area at the southern end of the base and the Operations (OPS) Area at the northern end of the base, with large portions of agricultural land situated between the two areas. The OPS Area is further divided into two areas: the main OPS Area (or just referred to as the OPS Area) and the Weapons (WPNS) Area. The ice pigging demonstration took place in the OPS and Weapons Area. A general site map of NASL is shown in Figure 4 whereas NASL's OPS Area is shown in Figure 5.

4.2 FACILITY/SITE CONDITIONS

NASL was selected based on a variety of criteria. The major focus was around the fact that it required an alternative and effective method for cleaning distribution lines to minimize the loss of water because of historical issues in meeting regulatory compliance with chlorine residuals. Because of its arid climate, the site would obtain faster payback due to its location in an area prone to water scarcity that necessitates the implementation of aggressive water conservation measures. Another important factor is that the site has long pipelines exceeding three thousand feet in length that would allow demonstration of ice pigging's ability to clean long pipes.

Members of project team are located within three hours of vehicle drive from NASL, thus having the benefit of easy site access and low travel costs. The site personnel were eager to reduce water wasted in flushing operations, and were very supportive to the ice pigging demonstration.

Figure 4. NASL Site Map

Figure 5. NASL OPS Area Site Map

5.0 TEST DESIGN

This section provides detailed description of the design and testing procedures that will be used to address the performance objectives.

- Fundamental Problem: DoD installations consume millions of gallons of potable water production through flushing of distribution pipes in order to maintain the required residual disinfectant levels throughout the water distribution system. This wasting of water to a large extent represents an opportunity to conserve water. The loss of disinfectant residuals can be attributed to the increase in disinfectant demands due to the presence of biofilms and exopolysaccharides on distribution pipe walls. The ice pigging technology to be validated in this project could provide a viable option for water main cleaning that can improve the ability to maintain disinfectant residuals and thereby reduce the need for frequent hydrant flushing. This new approach will conserve water compared to the current method of flushing that is inefficient and ineffective in controlling biofilms.

- Demonstration question: The main question to be answered with this demonstration is whether ice pigging technology can be used as a periodic maintenance tool to cost-effectively clean the water distribution system to maintain water quality, and thereby minimize water wastage through hydrant flushing operations.

5.1 CONCEPTUAL TEST DESIGN

An overview of key test variables in this demonstration is provided below.

- Hypothesis: Ice pigging can effectively clean potable water distribution systems and thereby assist in the maintenance of proper disinfectant residual levels without the need for excessive hydrant flushing as currently practiced.
- Independent variable: The use of the ice pigging operation that will remove accumulated deposits that harbor bacteria and biofilms that can exert disinfectant demand in water distribution system.
- Dependent variable(s): Quantity of deposits (sediment) removed per unit pipe area during ice pigging operations and biological activity of sediment removed; Residual chlorine and TTHM concentrations in the distribution system, chlorine consumption and the quantity of water required to be used in flushing post ice-pigging.
- Controlled variable(s): Water distribution network, water supply rates, and water consumption patterns are expected to remain the same pre- and post-ice pigging.
- Test Design: Baseline monitoring data will be developed and existing data will be gathered to characterize water quality conditions, chlorine consumption rates, and volumes of water used for flushing prior to ice pigging. Data on these parameters will be collected post ice-pigging for a period of one year. Performance assessment of the technology will be based on a comparison of baseline data with post-ice-pigging data. Cost of ice pigging operations including the cost of waste disposal will be collected and compared with benefits based on the gathered data.
- Test Phases: The test phases will be conducted as follows:

a. Baseline Monitoring: (i) Collect historical water quality data, water production rates, chlorine consumption rates, water meter readings on hydrant flushing; (ii) Install online sensors to monitor residual chlorine, turbidity, and hydrant flushing duration and time; (iii) Collect grab samples of hydrant flushing water to test for TSS in mg/L to quantify amount of sediments removed by current flushing operations.

b. Award Ice Pigging Contract: Survey the distribution system and select pipes in the network for ice pigging. A schedule of ice pigging runs, including the designated insertion/extraction hydrants, are shown in Table 6. Maps of the ice pigging runs showing the selected pipes for ice pigging are shown in Appendix C. Prepare an acquisition package for proposal solicitation. Evaluate proposal and award contract. We plan to award a single contract to perform both ice pigging and technical support tasks.

c. Perform Ice Pigging: Prior to commencement of ice pigging field works, send notifications on ice pigging works to affected customers. Mobilize rigs and perform ice pigging. Upon completion, all rigs will be demobilized, and water distribution system restored to normal operating conditions.

d. Post-Ice Pigging Monitoring: After ice pigging operations are performed, we will continue performance monitoring for a year or longer. We will continue to collect water quality data, hydrant flushing data, water production rates, and chlorine consumption rates.

e. Data Analysis and Reporting: Evaluate performance results based upon data collected during the demonstration. Analyze data to determine conformance with the Performance Objectives listed in Section 4. Perform life-cycle cost analysis to determine cost benefits of ice pigging technology. Prepare project and cost and performance reports.

5.2 BASELINE CHARACTERIZATION

Baseline data is needed to evaluate the performance and cost benefits of ice pigging. The baseline for this project is the current operating conditions of NASL's water distribution system.

- Reference Conditions: We plan to collect the following operational data representative of the current practice. Both historical records and online monitoring data will be collected.

  a. Amount of water used for conventional and nuisance flushing

  b. Amount of sediments removed by existing hydrant flushing operations and the chemical and biological characteristics of the sediments.

  c. Water consumption rate

  d. Residual chlorine and turbidity profile in water main

e. TTHM concentrations

f. Chlorine consumption rates

g. Number of customer complaints

- Baseline Collection Period: We plan to collect two years of historical data prior to the ice pigging operation. Online monitoring will be collected for 3 to 4 months, depending upon the schedule of the ice pigging operation. We plan to collect three monthly sampling events on hydrant flushing on the two hydrants designated for current flushing operations.

- Existing Baseline Data: Existing baseline data include amount of water pumped to the OPS Area, quarterly THM monitoring results, weekly biological test results, amount of liquid hypochlorite used in Building 50 (chlorine injection station in OPS Area).

- Baseline Estimation: The water and energy costs will be obtained from the utility rates charged by NASL to its customers to compute cost benefits for the NASL site. National average values will be used to analyze cost-effectiveness for applications nationwide.

- Data Collection Equipment: Online sensors for this demonstration are listed below.

a. Hydrant flow meter, ZPM Model FHM03

b. Hydrant flow monitoring system (fabricated in-house)

c. Analytical Technology, Inc (ATI) Q46H-62-1-1-3-1-1-1 free chlorine monitor with standard pH sensor and flow cell

d. ATI Q46/76-1-1-1-1-1 Turbidity monitor with Tungsten white light source and flow cell

e. HACH sc100 Controller

f. HACH CL17 Free Chlorine Analyzer

g. Omega OMYL-M34-4M dual channel process voltage/current input data logger

h. GPL-31XT Lifeline 12v 125 AH Deep Cycle Sealed AGM Battery

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 System Design

An ice pigging process schematic diagram is shown in Figure 3 in Section 2.1. Ice pigging system has three main components: ice making unit, ice delivery unit, and onboard monitoring system. The ice making unit is typically parked in a designated laydown area to produce ice needed for the operation. Each load of ice consists of approximately 2,700 gallons of water obtained from the site. NSF-60 certified sodium chloride (salt) is added to suppress freezing point of the ice. The ice making process is controlled by a PLC and is run overnight. After the completion of the ice making process, ice is pumped to an ice delivery unit for transporting to the job site. The delivery unit is parked close to an insertion hydrant for hose connection. SUEZ personnel will hook up hoses at the insertion and extraction hydrants. Ice slurry is pumped into the insertion hydrant while the extraction hydrant valve is operated to allow the displacement of water from introduction of the ice, and maintain the pressure above 20 psi in the main. When the proper amount of ice slurry is delivered, the insertion and extraction hydrant valves are closed. The upstream main line valve will be opened to supply the needed pressure to push the ice pig through the main. Once full system pressure is attained, operator opens the extraction hydrant valve to control the flow of water and monitor the progress of the ice pig. The discharge water flows through de-chlorination equipment into a sewer. Once the pig arrives, as detected by onboard sensors, the flow of water is diverted from the de-chlorination equipment into sewer. Water quality is monitored and water flow continues until the water quality readings return to the same values as the initial readings prior to the start of ice pigging. Upon completion, the insertion hydrant will be flushed to remove any ice that remains between the water main and hydrant. The downstream main valve will be opened and returned to full service.

5.3.2 Components of the System

Major components of an ice pigging system are listed below.

- An ice making unit
- An ice delivery unit.
- Ice Pigging flow control and water quality analysis system.
- Waste tanker truck to store waste ice and water for disposal for those pipe segments that do not have access to sanitary sewer connection. Table 6 shows the ice pigging runs and their disposal methods. As shown in the Table, almost half the runs will use waste tanker truck for disposal.

5.3.3 System Depiction

Figure 3 (in Section 2.1) shows a schematic of an overall ice pigging process. Figures 6 through 11 depict the main components of an ice pigging system and an ice pigging operation in action.

Figure 6. Making Ice On-Site

Figure 7. Isolating Valves Up- and Down-Stream

Figure 9. Inserting Ice Slurry into Upstream Hydrant

Figure 8. Extracting Ice at Downstream Hydrant

Figure 10. Collecting Samples during Ice Extraction

Figure 11. Samples of Ice Slurry during Ice Extraction

5.4 OPERATIONAL TESTING

- Operational Testing of Cost and Performance: Major activities involved with ice pigging operations include producing ice slurry onsite, transporting the produced ice to a job site, injecting ice into an upstream fire hydrant, extracting ice through a downstream fire hydrant, disassembling ice pigging connections and restoring the pipe segment to normal working conditions. Performance of ice pigging can be assessed by evaluating its ability to remove the accumulated sediments and debris on pipe walls. Samples collected during ice pigging will provide data needed to quantify the amount of sediments removed. Chemical and biological tests will provide data on the nature of the sediment to confirm biofilm removal. Actual costs for ice pigging, including mobilization/demobilization, ice pigging costs, utility personnel labor costs to support ice pigging operation, contract oversight costs, and administrative costs will be collected to determine the costs of ice pigging. Baseline and post-ice pigging monitoring data will be analyzed to determine water savings and improvement to water quality resulting from ice pigging.

- Modeling and Simulation: A hydraulic modeling study was performed in 2014 by Thomas Wright Inc., for NASL, to analyze the flow characteristics in the water distribution system pipes in the OPS Area. Results of water age calculations are shown in Figure 12. The modeling results confirmed the water quality issues that NASL has been experiencing. Water age is highest in the Weapons Area, followed by the air field and Hangar areas.

- Timeline: We conducted twelve days of ice pigging. Table 6 shows a schedule of daily ice pigging runs with insertion and extraction hydrant numbers. Figure 13 shows a map the ice pigging runs and detailed maps of daily ice pigging runs are attached in Appendix C.

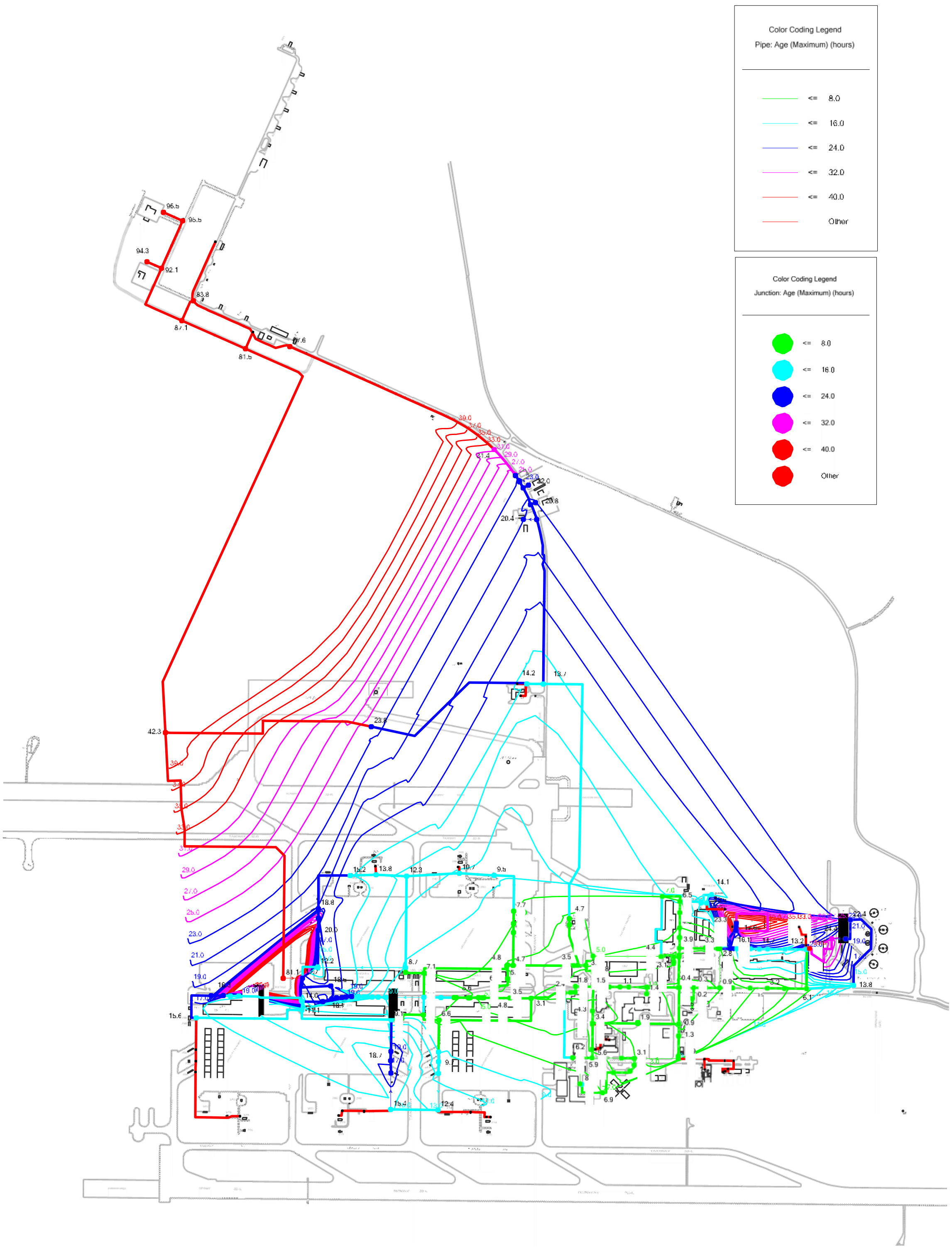

Figure 12. OPS Area Water Age Analysis

Table 6. Schedule of Ice Pigging Runs

Date		Run #	Insertion Point	Discharge Point	Disposal Method	Length (FT)	Pipe Dia. (in)	Pipe Material	Ice Quantity (Gals)
Day 1	Monday, April 18, 2016	OVERRUN	C43	C45	TANKER	3,400	12	AC	2700
Day 2	Wednesday, April 20, 2016	BLDG 417	C119	C118	TANKER	500	10	AC	300
Day 2	Wednesday, April 20, 2016	CALA	C45	C124	TANKER	3,250	10,12	AC	2200
Day 3	Saturday, April 23, 2016	TAXIWAY	C107	C44	TBD	820	8,16	AC	550
Day 3	Saturday, April 23, 2016	ORDNANCE CIRCLE	C122	C120	TANKER	3,050	6,10	AC	2100
Day 4	Monday, April 25, 2016	REEVES	C124	C74	TANKER	6,100	10,14	AC	2700
Day 5	Wednesday, April 27, 2016	SUSPECT CARGO	C124	C122	TANKER	6,500	10	AC	2700
Day 6	Saturday, April 30, 2016	ORDNANCE RD 1	C116	C110	TANKER	3,625	10	AC	2250
Day 7	Monday, May 02, 2016	RUNWAY	C74	C124	TANKER	6,100	10,14	AC	2700
Day 8	Wednesday, May 04, 2016	HANGARS 3 & 5	C122	C124	TANKER	6,500	10	AC	2700
Day 9	Saturday, May 07, 2016	ORDNANCE RD 2	C45	C110	TANKER	2,200	10,12	AC	1400
Day 9	Saturday, May 07, 2016	ORDNANCE RD -CIRCLE	C116	C115	TANKER	2,050	10	AC	1200
Day 10	Monday, May 09, 2016	AIRCRAFT PK 1	C77	C83	SEWER	5,100	8,14	AC	2700
Day 11	Wednesday, May 11, 2016	AIRCRAFT PK 2	C48	C83	SEWER	1,500	8,14	AC	850
Day 11	Wednesday, May 11, 2016	AIRCRAFT PK 3	C56	C86	SEWER	2,950	8,14,16	AC	1800
Day 12	Friday, May 13, 2016	HANGAR 2	C36	C77	TANKER	2,200	16	AC	2700

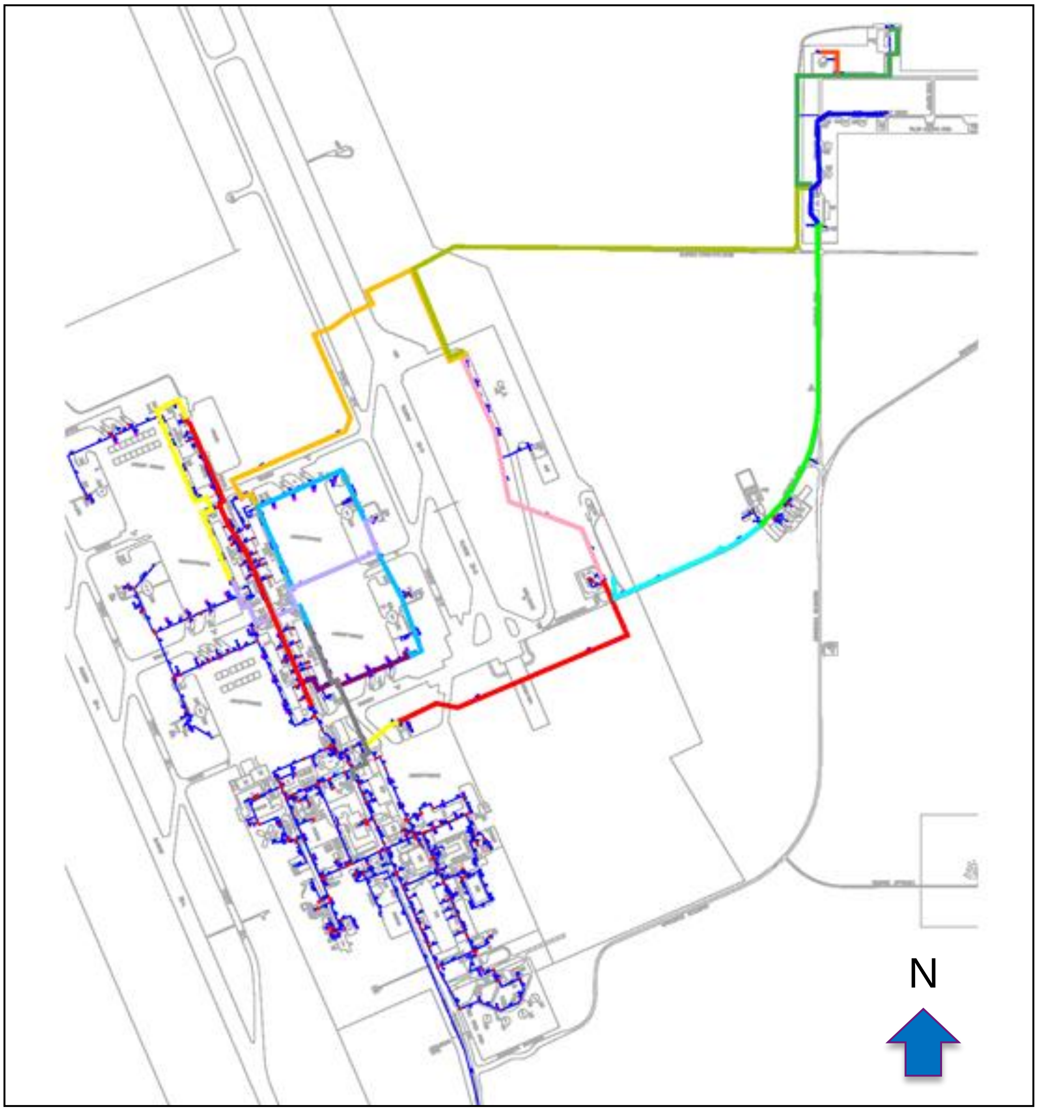

Figure 13. Map of ice pigging runs.

5.5 SAMPLING PROTOCOL

5.5.1 Data Description

Baseline and Post-Ice Pigging Sampling

The sampling protocol to collect data for baseline and post-ice pigging monitoring is shown in Table 7. These two phases of monitoring are needed to compare the distribution system operating conditions and its water quality before and after ice pigging. Main water quality parameters monitored include free chlorine, pH, water temperature, turbidity, and TTHM. System operating parameters to be collected include amount of water used in hydrant flushing, liquid sodium hypochlorite used for water disinfection in the OPS Area, and amount of water pumped to the OPS Area. Furthermore, samples of hydrant flushing water will be collected and tested for constituents listed in Table 4 for comparison with ice pigging water analysis results.

Table 7. Sampling Protocol for Pre- and Post-Ice Pigging Monitoring

Data Description	Data Collector	Data Recording	Data Collection Frequency
Free chlorine	EXWC/NASL	Automatic and Manual	Every minute and weekly
Turbidity, pH, water temperature	EXWC	Automatic	Every minute
TTHM	NASL	Manual	Once a month
Amount of water used in hydrant flushing	NASL	Manual	Monthly
Hydrant flushing time and duration	EXWC	Automatic	Every minute
Liquid Sodium Hypochlorite consumption rate	NASL	Manual	Monthly
Water pumped to OPS Area	NASL	Manual	Daily
Sediment and other water quality for hydrant flushing water	EXWC	Manual	Every 30 seconds the first 5 minutes, every 5 minutes from 5-30 minutes

Ice Pigging Sampling

Sampling protocol for data collection during ice pigging runs is shown in Table 8. Three types of samples will be taken during the runs: routine samples, additional bacterial samples, and onboard monitoring.

Routine samples are taken for each run to determine the amount of sediments removed and general chemical and biological characteristics of the materials removed from water mains. Grab samples for routine sampling will be collected every 30 seconds as the ice is discharging. Samples will be sent to a laboratory to be analyzed for parameters listed below.

- Total Suspended Solids
- pH
- Total Iron
- Total Manganese
- Free Chlorine
- Total Phosphate
- TOC
- HPC
- Coliform
- Iron Reducing Bacteria
- Sulfate Reducing Bacteria

For a selected number of runs, additional bacterial samples are to be collected for further bacterial analysis. There will be five sets of additional samples collected from five selected pipe loops that are representative of the challenging areas that might be vulnerable to water quality issues. Each set of samples will include grab samples at 2 to 4 minutes before ice arrival, and 30s, 60s, 120s, and 240s after ice arrival. Samples will be sent to a specialty laboratory for bacterial community analysis through 16S rRNA gene sequencing to obtain information on predominant bacteria in the biofilms. The ice pigging runs and pipe loop areas selected for this analysis are listed below.

- Day 4 (Reeve 1), Hangers #1, 3, and 4
- Day 7 (Grangeville Road 3): Weapons Area
- Day 6 (Reeve 2): Hangers #3 and 5
- Day 10 (Aircraft Parking 1): aircraft parking
- Day 12 (Hanger 2)

Onboard monitoring system monitors water quality during ice pigging run for process control. Parameters monitored include: turbidity, conductivity, water temperature, and water flow rate.

Table 8. Sampling Protocol during Ice Pigging Operation

Data Description	Data Collector	Data Recording	Data Collection Frequency
Routine ice pigging samples	SUEZ	Manual	Every 30 seconds during ice discharge
Additional bacterial samples	SUEZ	Manual	Six per run for five runs
Onboard water monitoring	SUEZ	Online	Every minute for each run

5.5.2 Data Collector

Data collection will be performed by personnel from EXWC, NASL, and SUEZ. For baseline and post-ice pigging monitoring, EXWC and NASL will be responsible for the data collection. EXWC will collect online sensor data, including free chlorine, pH, water temperature, turbidity, and hydrant flushing time and duration. NASL will collect distribution system operational conditions and compliance monitoring data, including TTHM, free chlorine analysis, amount of water used for hydrant flushing, and amount of water pumped to OPS Area. SUEZ personnel will be responsible for the data collection during ice pigging runs, including routine ice pigging sampling, additional bacterial community analysis sampling, and onboard water quality monitoring.

5.5.3 Data Recording

As listed in Tables 7 and 8, data will be recorded either manually or automatically. Baseline and post-ice pigging manual data will be recorded in the NASL Water Plant's log notebook. Data from online sensors for baseline and post-ice pigging monitoring are automatically recorded in data loggers. During ice pigging operation, manual data will be recorded in log notebook maintained by SUEZ personnel and onboard sensor data are recorded to the data logger.

5.5.4 Data Storage and Backup

Data stored in the Omega OMYL-M34-4M data loggers will be downloaded to a laptop computer via Omega View Plus software that comes with the data logger. Raw data files are stored as delimited text files and are easily imported into Microsoft Excel or other software for data analysis and graphical display. Raw data will be downloaded from data loggers bimonthly. After each download, the data files will be saved to an external hard drive and EXWC's secured network drive for data backup as well as sharing. Manual data are entered into computer files, such as Excel files, for storage in computer disk drives, with backup in an external hard drive and network drive.

5.5.5 Data Collection Diagram

Figure 14 shows location of data collection within the OPS Area.

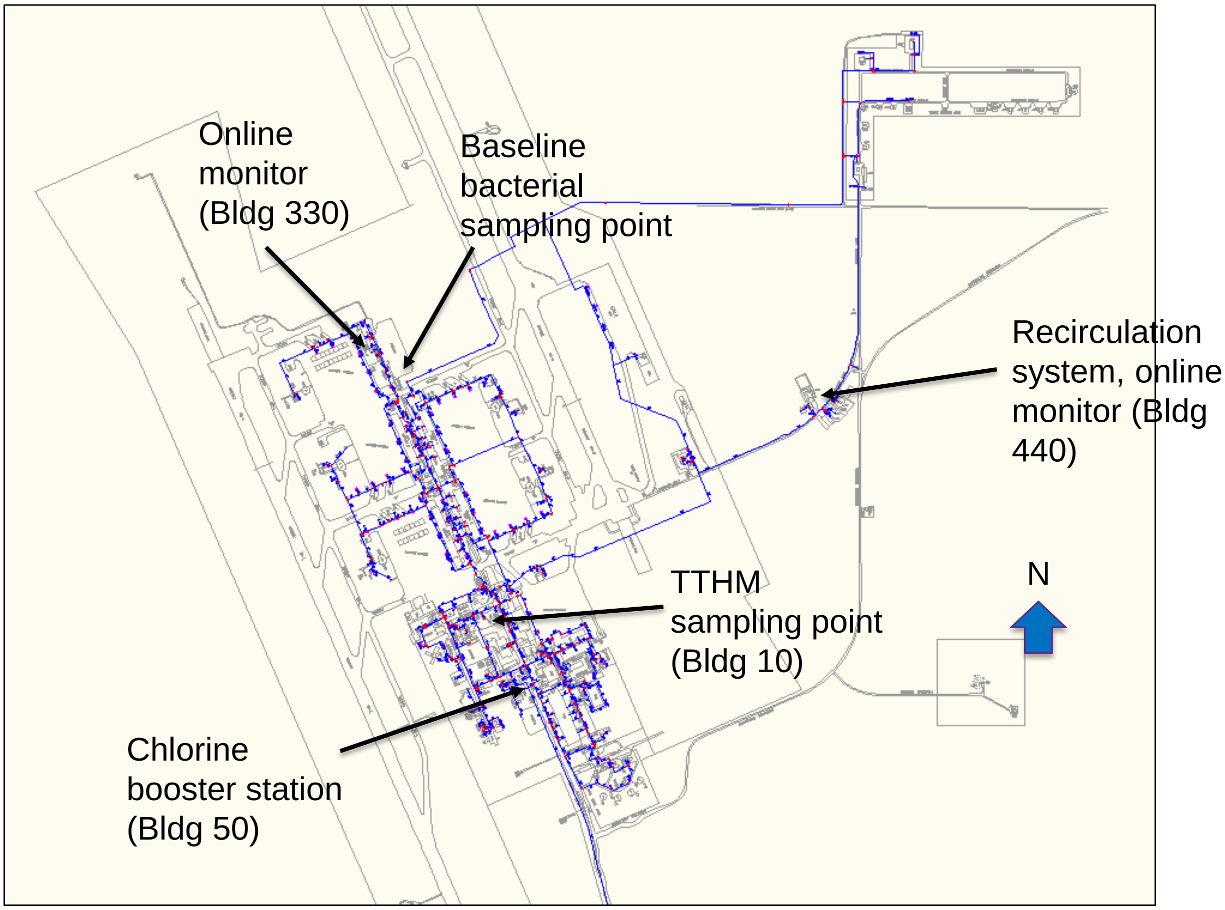

Figure 14. Locations of Data Collection

5.6 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

- Online sensors will be calibrated in accordance with Table 9.
- We plan to record online data every minute via data loggers.
- For field water sampling, EPA standard test method protocol will be followed. Grab samples will be stored and chilled in coolers for overnight shipment to laboratory for analysis.

Table 9. Online Sensor Calibration Schedule

No.	Sensor Type	Calibration Method	Frequency
1	Free chlorine	Compare with handheld DPB method	Bimonthly
2	pH	pH standard (pH 4, 7, 10)	Bimonthly
3	Turbidity	Turbidity standard (20 NTU)	Bimonthly

5.7 SAMPLING RESULTS

Sampling results are summarized in Section 6 to facilitate evaluation of technology performance and assessment of performance objectives.

6.0 PERFORMANCE ASSESSMENT

Section 3 summarizes the performance criteria and results. Sections below provide more detailed results and discussions.

The details of the ice pigging locations, insertion and discharge hydrants, and pipeline information are given in Table 6 under Section 5.4. The pipe diameters varied from 8” to 16”, and the pipe lengths pigged varied from 500 ft to 6,500 ft. Five of the lines pigged had changes in pipe diameters along the length of the pipe. The ice pig was able to navigate through these pipe changes without any apparent problems.

6.1 REDUCTION OF WATER USED IN HYDRANT FLUSHING

Table 10 summarizes quantities of water used in hydrant flushing in the OPS Area before and after ice pigging. Water volumes were obtained from water meter readings for period from June 2015 to November 2016. Water meters were not recorded after November 2016 and water volumes for that period were calculated from the hydrant flushing schedule set for that period.

Annual water saving post-ice pigging is 2.3 million gallons per year or 57.5% compared to the baseline water flushing volume. The flushing schedule set after ice pigging represents the bare minimum flushing requirement for proper water distribution system operation.

Although the total water usage for the year was reduced, there were two months (April and May) at the end of the demonstration period when post-ice pigging values exceeded the baseline values. The reason for that was the water service to part of the distribution system (Hangar No. 5 area) was shutoff during April and May in 2016 due to construction activities. The automatic flusher in that area was also shutoff, resulting in lower water consumption for those two months. The water service and flusher were put back in service in June 2016.

The baseline water consumption numbers vary widely over the year likely due to the unsteady system performance during that period. Water flushers automatically adjusted the duration of flushing corresponding to the residual levels. Operators also adjusted the frequencies of the flushers responding to the levels of residual in the dead-end areas. The fluctuation of the water consumption numbers reflects the difficulty in maintaining adequate residuals.

During post-ice pigging period, system performance was more steady. Operators reduced the flushing frequency gradually after seeing improvement in both the residual and TTHM.

Table 10. Water Used in Hydrant Flushing in OPS Area

Date	Pre-Ice Pigging (Gal/Month)	Date	Post-Ice Pigging (Gal/Month)
Jun-15	240,800	Jun-16	100,100
Jul-15	337,000	Jul-16	321,700
Aug-15	474,200	Aug-16	323,900
Sep-15	481,300	Sep-16	377,600
Oct-15	546,400	Oct-16	312,000
Nov-15	832,200	Nov-16	69,400
Dec-15	653,800	Dec-16	144,000
Jan-16	1,020,200	Jan-17	144,000
Feb-16	498,200	Feb-17	128,000
Mar-16	235,600	Mar-17	144,000
Apr-16	97,000	Apr-17	136,000
May-16	84,900	May-17	136,000
	-----		-----
Annual Total (Gal/Year)	5,501,600		2,336,700
Water Reduction (Gal/Year)			3,164,900
Percent Reduction			57.5%

6.2 CLEANING EFFECTIVENESS

6.2.1 Sediment Removal

Sediment removal data for the ice pigged lines were collected by SUEZ, and the data as provided by SUEZ are given and discussed in this section. The data collected by SUEZ include flow rate, temperature, conductivity, and the sediment load. The first three parameters were recorded every minute from just prior to the arrival of ice to up to 22 minutes, and samples were collected every minute for subsequent analysis for sediment load. The imminent arrival of the ice pig was estimated from the conductivity readings, and a value of approximately 4 mS/cm was used as the starting point.

Table 11 shows the amount of sediment, biofilm, and other debris removed from the pipeline during the course of ice pigging. The quantity of ice used, the temperature, and the salt content of the ice were determined by SUEZ based on individual pipe requirements at the site.

The sediment removal depends on a number of factors including the characteristics of the pipeline and the ice pigging process. The pipe and water characteristics include factors such as the length and diameter of the pipeline, water age, and past maintenance practices. The volume of ice used, the ice fraction, and the temperature, and conductivity of the ice will also affect the amount of sediment and biofilm removed. The data show that there is a wide variation in the amount of sediment removed per mile of pipe cleaned, ranging from 8.3 lbs/mi to 81.8 lbs/mi. When adjusted for the pipe surface cleaned, the sediment removed ranges from 0.27 g/ft2 to 2.68 g/ft2. The sediment removed is reasonably consistent when adjusted for the volume of ice used.

Table 11. Sediment Removal Data

Date	Location	Ice vol. (gals)	Ice (%)	Sediment removed (lb)	Sediment (lb/mi)	Sediment (g/ft^2)
5/9/16	Aircraft Pk 1	2700	90	13.81	14.32	0.509
5/11/16	Aircraft Pk 2	850	90	7.45	26.26	0.820
4/20/16	Bldg 417	300	90	7.74	81.83	2.676
4/20/16	CALA	2200	90	10.19	16.58	0.542
5/13/16	Hangar 2	2700	90	18.21	43.79	0.894
5/7/16	Ordnance Rd 2	1400	90	5.52	13.27	0.433
5/7/16	Ordnance Rd Cir	7810	90	13.11	33.82	2.443
4/25/26	Reeves	2700	90	11.34	9.83	0.315
4/27/26	Suspect Cargo	2700	90	10.21	8.31	0.272

The sediment removal rate can be seen from the plots of sediment removed as a function of time. The removal rate is a function of the local operating procedure and the variables noted above. The data for Aircraft Park 1 and Aircraft Park 2 are shown in Figures 15 and 16. These data show peak sediment production at about 400 s. The sediment removal distribution and the peak are a function of the length of the pipeline, strength of the attached biofilms and deposits, the volume of ice used, and the consistency of the ice slurry. Thus Aircraft Park 2 has a fairly sharp distribution whereas Aircraft Park 1 has multiple peaks and a broader distribution. This is in part due to the fact that 2,700 gallons of ice was used in the pigging of Aircraft Park 1 line with a line length of 5,100 feet, whereas 850 gals of ice were used in the case of Aircraft Park 2 with a line length of 1,500 ft.

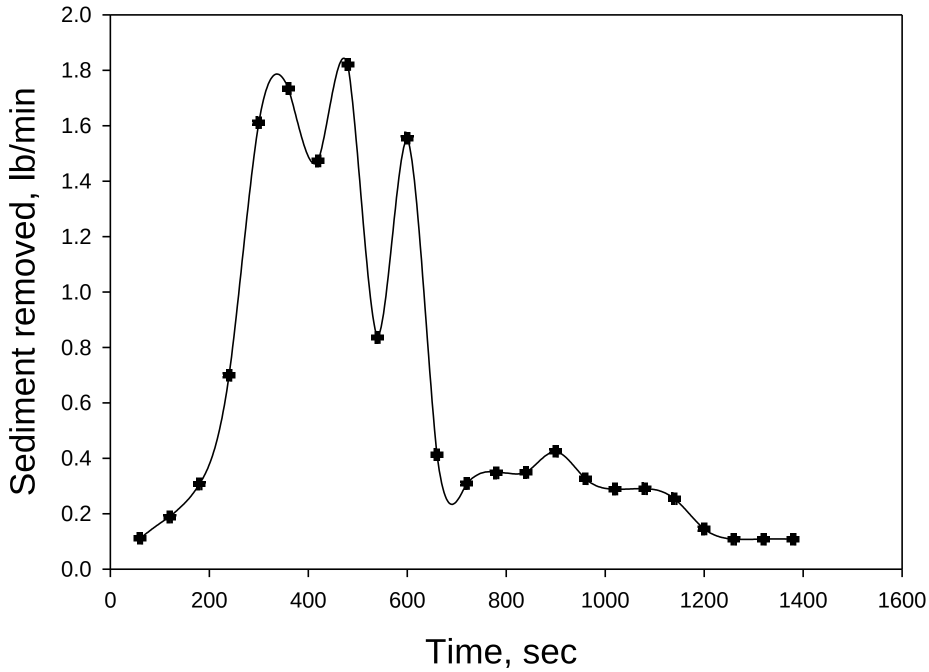

Figure 15. Sediment removed, Aircraft Park 1

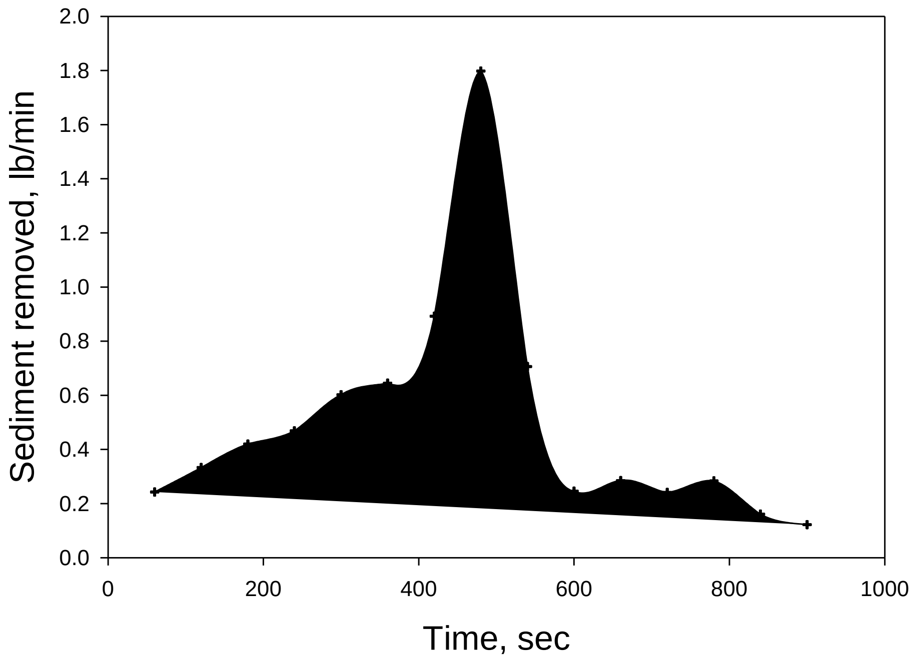

Figure 16. Sediment removed, Aircraft Park 2

The sediment removal data for Building 417 is shown in Figure17. This is a short line of about 500 feet in length. The ice pig was small as only 300 gallons of ice was used. A sharp peak is observed at about 200 seconds in this case. In the case of CALA run, the sediment release is spread over a long period from 200 to 1, 200 seconds with multiple peaks as shown in Figure 18. This is in part due to the relatively larger volume of ice used relative to the length of the pipe for ice pigging. Other results are observed to be similar to the above cases and are shown in Appendix E.

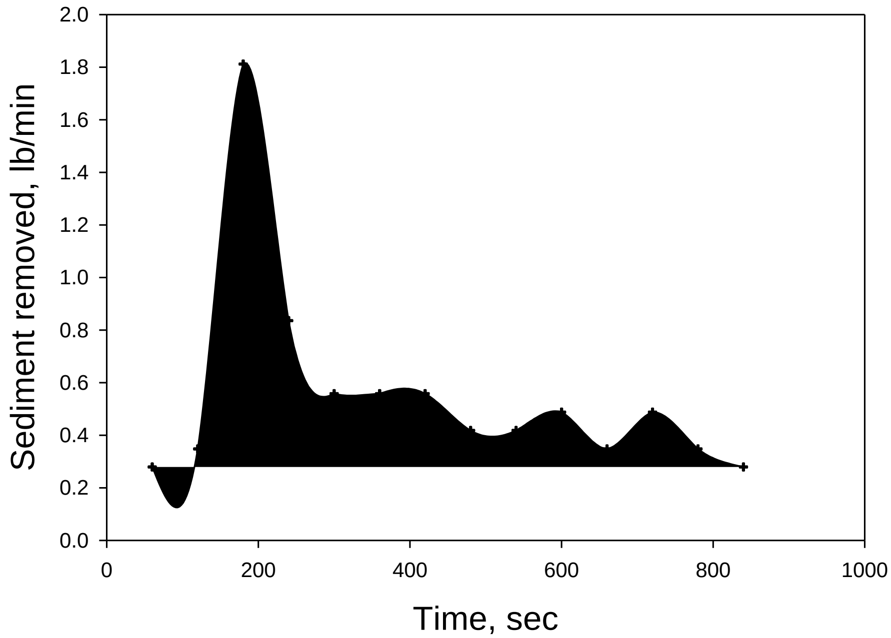

Figure 17. Sediment removed, Building 417

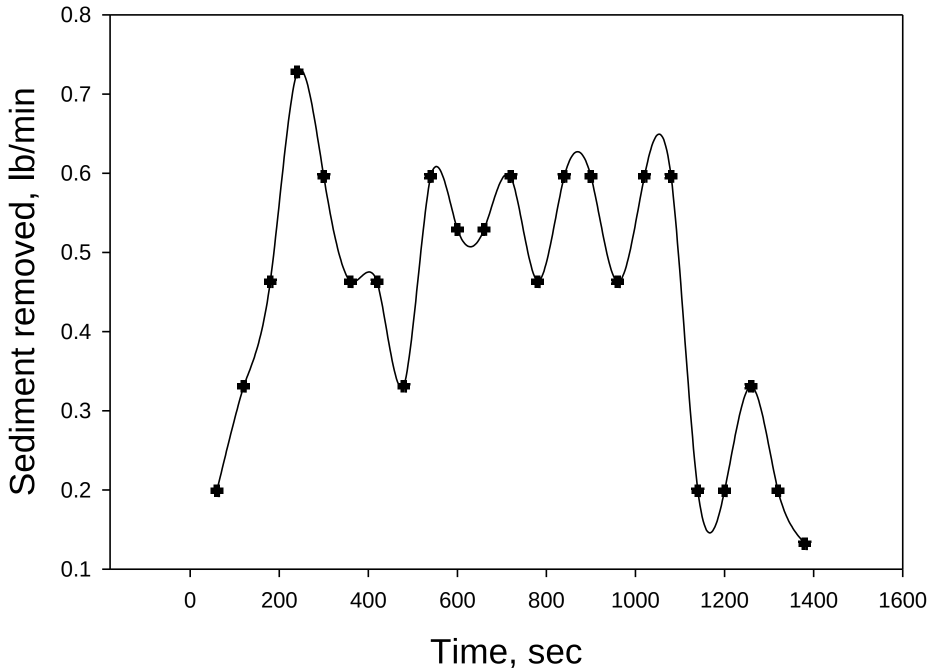

Figure 18. Sediment removed, CALA

6.2.2 *Chemical and Biological Data*

Chemical and biological parameters were analyzed for water samples collected before ice pigging from a hydrant flusher located near Hangar 5, and after ice pigging from the respective pipelines that were cleaned. This information is used to characterize the changes that can be anticipated to occur after cleaning by ice pigging. Table 12 shows data obtained during hydrant flushing at Hangar 5 on March 17, 2016. HGR1 and HGR2 denote samples taken three minutes apart. The data show a high chlorine residual level, and an average TOC of 0.82 mg/L. Metals and bacteria analyzed for were at non-detect levels. Table 13 shows data obtained from hydrant flushing on April 17, 2016 baseline sampling. These data are similar to those of samples from March 17, except for somewhat lower level of TOC in the first sample. The metals were non-detect, as well as coliform bacterial and HPC. Additional twenty samples were collected during baseline hydrant flushing and analyzed at one minute intervals for chlorine residual, TSS, *E. Coliform*, and total coliform. The results show that chlorine residual varied from 1.6 mg/L to 1.9 mg/L during this period, but the other parameters were at non-detect levels.

Table 12. Sampling Data Pre-Pigging from Hydrant Flush at Hangar 5, 17 March 2016

Samples	Chlorine residual	pH	P	TOC	TSS	Fe	Mn	E. Coli	Total Coliform	HPC^{+}
HGR1	1.8	8.1	0.16	0.96	ND	ND	ND	<1.1	<1.1	<1
HGR2	1.8	8.2	0.14	0.67	ND	ND	ND	<1.1	<1.1	<1

Note: All chemical parameters except pH are in mg/L

*MPN/100 mL

$^{+}$ 1 CFU/mL

Table 13. Sampling Data Pre-Pigging from Hydrant Flush at Hangar 5, 7 April 2016

Samples	Chlorine residual	pH	P	TOC	TSS	Fe	Mn	E. Coli*	Total Coliform*	HPC^{+}
HG1	1.8	8.0	0.13	0.73	ND	ND	ND	<1.1	<1.1	<1
HG2	1.8	8.0	0.13	0.67	ND	ND	ND	<1.1	<1.1	<1

Note: All chemical parameters except pH are in mg/L

*MPN/100 mL

$^{+}$ 1 CFU/mL

The chemical and biological data from pigged pipes at various locations is shown in Table 14. Residual chlorine levels ranged from a low of 0.89 mg/L at Building 417 to a high of 5.1 mg/L at the Runway location. The average chlorine residual at 2.3 mg/L is higher than typical residual due to construction activities in the OPS Area. The pH of the water ranged from 7.7 to 8.6 in the different lines. Orthophosphate levels were non-detect in all the lines. The TOC levels were in most cases consistently lower compared to hydrant flushing TOC levels. The average TOC for all pipelines is 0.44 mg/L. The TSS levels ranged from a low of 70 mg/L at Aircraft Park Road to a high of 410 mg/L at Ordnance Road Circle. The average TSS for all pipes is 247 mg/L. In comparison, the TSS levels were non-detect from the hydrant flushing samples as shown in Tables 12 and 13. These data indicate that considerable amount of sediment and TOC was removed during ice pigging. Table 14 also shows that iron and manganese were present in significant amounts in the post-pigged water. The iron levels ranged from 3.2 mg/L to 94 mg/L whereas the manganese levels ranged from 0.19 to 2.1 mg/L. These levels indicate considerable precipitation and accumulation of these metals in the lines over the long time period the distribution system was in operation without cleaning. In comparison, the iron and manganese levels were non-detect in the hydraulic flushing samples indicating that the flushing velocities were insufficient to dislodge these deposits.

The E. Coli and total coliform levels were zero in all samples due to the high levels of residual chlorine. However, HPC counts were positive in ten of the lines pigged indicating the viability of some bacteria in the pipelines. This is potentially due to shielding from disinfectants of these bacteria in biofilms. Ordnance Circle had particularly high HPC counts at 160 CFU/mL. In contrast, hydraulic flushing showed no HPC counts, and indicates the inability of hydrant flushing to remove biofilms and the associated bacteria. Hydraulic flushing will remove lose bacteria at the water-biofilm interface, but not the entrenched bacteria close to the pipe interior surface. A more detailed analysis is given in the section on bacterial community analysis.

Table 14. Sampling Data during Ice-Pigging from Ice-Pigged Locations

Location	Chlorine residual	pH	PO_4	TOC	TSS	Fe	Mn	E. Coli	Total Coliform	HPC
Bldg 417	0.89	8.3	ND	0.67	190	23.0	0.37	<1.1	<1.1	<1
CALA	1.6	8.0	ND	0	200	9.7	0.3	<1.1	<1.1	3
Taxiway	3.2	7.8	ND	0.51	170	33.0	1.6	<1.1	<1.1	<1.1
Ordnance Circle	3.2	7.8	ND	0.27	140	20.0	0.61	<1.1	<1.1	160
Reeves	3.2	7.9	ND	0.63	160	12.0	0.85	<1.1	<1.1	8
Suspect Cargo	1.8	7.7	ND	0.43	120	13.0	0.65	<1.1	<1.1	2
Ordnance Rd 1	2.3	8.0	ND	0.37	220	6.2	0.56	<1.1	<1.1	5
Runway	5.1	8.0	ND	0.42	320	28.0	1.1	<1.1	<1.1	1
Hangar 3&5	1.8[a]	8.0	ND	0.73	760	94.0	2.1	<1.1	<1.1	<1
Ordnance Rd 2	1.9	8.1	ND	0.64	98	3.7	0.47	<1.1	<1.1	1
Ordnance Rd Cir	1.2	8.1	ND	0.32	410	7.3	0.19	<1.1	<1.1	4
Aircraft Park 1	1.8	8.1	ND	0.44	350	52.0	0.72	<1.1	<1.1	5
Aircraft Park 2	1.6	8.6	ND	0.3	70	4.2	0.24	<1.1	<1.1	3

Note: All chemical parameters except pH are in mg/L
[*] MPN/100 mL
[+] 1 CFU/mL
[a] From four samples at Hangar 5, 3/17/16 and 4/7/16; One sample at 3.4 mg/L, 5/4/16

6.2.3 Bacterial Community Analysis

6.2.3.1 Bacteria in Water Distribution Systems

The potential regrowth of microorganisms in drinking water distribution systems is a major concern for utility managers in assuring water free of microbiological contaminants at the consumer's tap. Bacteria can exist in water distribution pipeline in planktonic form (free cells in water) or as a unit attached to a surface as biofilm or within the confines of the biofilm. A biofilm consists of microbial communities attached to a surface or embedded in an organic polymeric matrix of microbial origin. Many bacteria can attach to surfaces using flexible appendages and the excretion of exopolysaccharides (EPS) to form an extracellular matrix. The hydrated extracellular matrix accounts for about 50% to 90% of the biofilm. EPS forms a cohesive surface that provides habitat for cells and adhesion to the surface. EPS also can exert chlorine demand thereby affecting disinfectant residuals.

The ability to meet minimum requirement set forth in the national standards for disinfectant residual levels and TTHM levels can be compromised by the growth of microorganisms and biofilms in the distribution pipelines. Maintaining disinfectant residual levels, typically chlorine, is a common method employed to control bacterial regrowth in distribution systems. Several studies have shown that despite the use of disinfectants for the control of microorganisms, regrowth occurs in pipelines, and these microorganisms cannot be typically identified using the conventional coliform tests or HPC count tests (Douterelo et al, 2016; Revetta et al, 2010). In this study, bacterial community structure in water distribution pipelines at NASL was assessed using 16S rRNA sequencing procedure. 16S ribosomal RNA is present in most microorganisms, and the 16S rRNA sequences for most bacteria and archaea are widely available in databases. Next generation sequencing (NGS) is a culture-free method that is currently available to assess microbiomes in water distribution systems.

The extent of biofilm formation and the microbial community structure will be influenced by many factors including the pipe material, the source of water, finished water quality, and the type of disinfectant and disinfectant concentration used. An increase in flow velocity, water temperature, or nutrient concentration may also facilitate increased biofilm formation and growth.

The five pigged pipelines from which samples were collected for bacterial community analysis are asbestos cement pipes (ACP). ACP surface is alkaline with a surface pH higher than 11. This high pH is generally not conducive to the growth of microorganisms. However, this high alkalinity can be neutralized to some extent by the dissolved components in the water such as chloride, sulfate, etc. In addition, several groups of bacteria can secrete acids and exopolysaccharides (EPS) to create a more habitable environment under these adverse conditions. Wang et al (2011) examined excavated ACPs that were in service for approximately 52 years from a Canadian water distribution system. Examination of the open pipes revealed a 3 mm to 5 mm biofilm which was classified into four layers. Layer A was closest to the pipe wall surface, and layer D was the thin layer at the biofilm water interface interacting with the flowing water. Sublayers B and C are in between A and D. Of the total bacteria, 68.7% were in sublayer A, 28.4% in sublayer B, 1.2% in sublayer C, and 1.7% in sublayer D. About 95.5% of the bacteria were associated with slime forming bacteria, 1.6% were iron-related, 1.4% were heterotrophic, and 0.4% were acid producing bacteria. Sublayers A and B combined was 94.9% of the total bacteria. Thus, much of the bacteria (~95%) were associated with biofilms close to the pipe surface.

The implications of the above for ice pigging of pipelines at NASL is that, one can expect the ice pig to dislodge different layers of biofilm as the plug travels through the pipeline. Sampling at different time intervals from the ice slurry arriving at the discharge hydrant can provide a signature of the microbial composition of the biofilms in the pipeline. Bacteria forming biofilms closest to the pipe surface are likely to be species that can cope with the high surface pH of ACP, and bacteria that can mineralize silicate and other constituents of the ACP.

6.2.3.2 Ice Pigging Bacterial Sampling Protocols

The schedule of ice pigging operations at NASL is shown in Table 6. Samples were collected for microbial community analyses for five selected events conducted over five different days. Samples were collected on Days 3, 4, 8, 10 and 12 during ice pigging events at Ordnance Circle, Reeves, Hangars 3 and 5, Aircraft Park 1, and Hangar 2 respectively. These sites were chosen based on previously reported high TTHM concentrations, and to provide pipes with a range of water ages. The insertion and discharge fire hydrant locations are also given in Table 6. The water ages ranged from eight hours to more than 40 hours. Two baseline samples were also collected from hydraulic flushing operations at Hangar 5 at 60 and 120 seconds after the start of flushing.

Five samples were collected for bacterial community analyses from each ice pigging run. One sample was taken 120 to 240 seconds before ice arrival (denoted as sample at zero seconds), and thereafter samples were taken at 30, 60, 120, and 240 seconds from the initial arrival of the ice pig. Samples were collected in 120 mL sterile bottles containing sodium thiosulfate for de-chlorination. The collected samples were immediately placed in ice packs and shipped overnight to Omega Bioservices in Atlanta, GA for DNA extraction and metagenomics analysis. Samples taken on Saturdays were frozen and shipped with other samples from runs the following Monday. The DNA from the samples, library workflow preparation, sequencing, and data interpretation were performed by Omega Bioservices using the Illumina MiSeq platform.

6.2.3.3 Bacterial Community Analysis Results

The relative abundance taxonomic data are given for microorganism groupings from the kingdom level to the species level. The data for all samples including hydraulic flushing indicate that greater than 99% of the organisms in all cases are bacteria. There is no indication of the presence of any viruses. The data are grouped into six classifications beginning with phylum level and ending with bacterial species. In the description below, the phylum level groupings along with a description of the predominant bacterial species are provided.

<u>Ordnance Circle</u>

This section of the pipe has high water age values, with maximum water age being reported as ranging from 84 hours to 96 hours (Thomas/Wright Inc., 2014). The flow velocities are low, and chlorine residual was measured at 2.1 mg/L.

Firmicutes form the major group of bacteria at the phylum level, followed by proteobacteria. Firmicutes are gram positive bacteria that can adapt to low nutrient and adverse environmental conditions. The fact that the bacterial composition is high in firmicutes at all-time intervals indicates that this group of bacteria dominated the biofilm from the surface of the pipe to the water interface. Proteobacteria is found to be the second most abundant group, and was present in all layers of biofilm though less abundant than firmicutes. Proteobacteria were most abundant in the sample at the 60 second time period indicating this group to be a major component of the middle portion of the biofilm. Other groups of bacteria present to a lesser extent include bacteriodetes, actinobacteria, and cyanobacteria. A stacked bar chart of the relative abundance of identified bacteria is shown Figure 19.

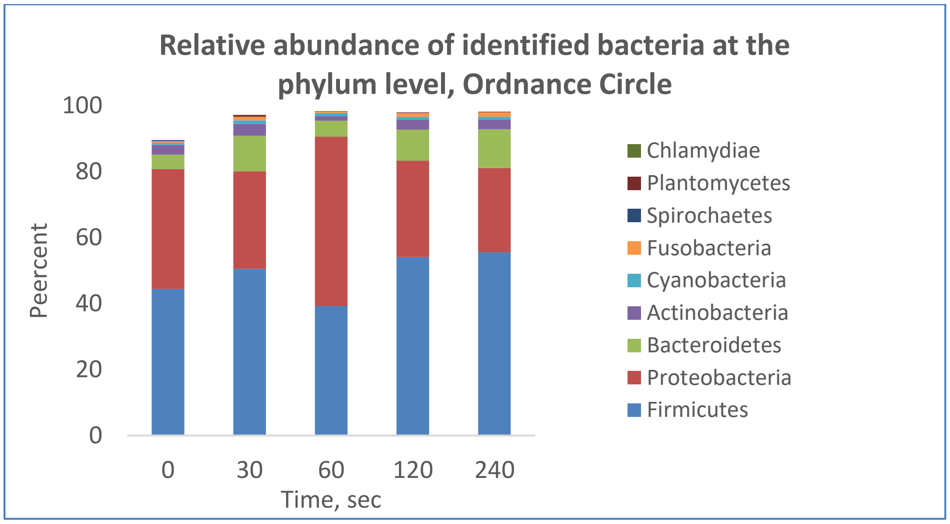

Figure 19. Relative Abundance of Identified Bacteria at the Phylum Level, Ordnance Circle

Tables 15 and 16 show the relative abundance in percent of bacteria at the phylum and species levels, respectively. Bacilli dominate the firmicute group of bacteria at the class level at 37.8% to 52.5% levels over the 240 second sampling period. Clostridia, another firmicute is present at less than 1.4 to 2.9% level in the 30 to 240 seconds samples. Proteobacteria sub-classifications, alphaproteobacteria, betaproteobacteria, and gammaproteobacteria were present in all samples, while deltaproteobacteria were present only in the zero second sample prior to ice pig arrival.

Table 15. Relative abundance (%) of Bacteria at the Phylum Level at Different Sampling Times at Ordnance Circle*

	Sampling time, secs				
Classification	0	30	60	120	240
Proteobacteria	30.66	29.49	27.46	16.09	16.26
Firmicutes	23.3	33.41	29.97	55.49	57.33
Planctomycetes	11.99	6.06	8.19	1.85	1.14
Actinobacteria	5.96	7.36	8.29	3.18	4.22
Chlamydiae	5.19	2.99	4.19	0	0
Bacteriodetes	4.15	4.78	3.39	1	0.63

*Only major phyla are shown

Table 16. Relative Abundance (%) of Bacteria at the Species Level at Different Sampling Times at Ordnance Circle*

	Sampling time, secs				
Classification	0	30	60	120	240
Bacillus safensis	21.31	19.03	16.33	20.96	22.8
Bacillus mucillaginosus	7.3	10.6	7.81	10.55	10.64
Geobacter sulfurreducens	7.15	0	0	0	0
Enterobacter cowanii	3.02	3.07	0	2.83	3.78
Bacillus cereus	2.5	2.71	2.42	3.54	3.07

*Only major species are shown

<u>Reeves</u>

The maximum water age ranges from 3.5 to 15 hours (Thomas/Wright Inc., 2014), and the chlorine residual was measured at 3.1 mg/L. The relative abundance in percent of bacteria at the phylum level is shown in Table 16. The zero second sample contained proteobacteria at the highest level followed by firmicutes, plantomycetes, actinobacteria, and chlamydiae in that order. For the subsequent samples the levels of proteobacteria progressively decreased while the levels of firmicutes increased. actinobacteria, and chlamydiae in that order. At the 120 and 240 seconds samples, 55.5% and 57.3% of the bacteria were firmicutes. A decreasing trend is also observed for the other bacterial phyla such as planctomycetes, actinobacteria, and chlamidyiae. This indicates that the biofilm layer close to the pipe surface is mainly populated with firmicutes, several species of which are known to tolerate the alkaline environment and silicate mineral composition of the asbestos cement pipes.

The bacterial species analysis is given in Table 17, and indicates *B. safensis* as the predominant specie through all sampling time periods. *B. safensis*, *B. mucillaginosus*, and *B. cereus* are the predominant species at the 240 seconds time period indicating that these species predominate at the pipe surface, and the other species are all at less than 2% levels. These results are similar to those for Ordnance Circle samples.

Table 17. Relative Abundance (%) of Bacteria at the Species Level at Different Sampling Times at Reeves*

	Sampling time, secs				
Classification	0	30	60	120	240
Bacillus safensis	5.37	8.58	7.86	19.39	20.85
Bifidobacterium bombi	3.76	1.22	1.87	0	0
Bacillus mucillaginosus	3.5	5.27	4.35	12.78	12.29
Lutebacter anthropi	3.17	0	0	0	0
Isophaera pallida	2.12	0	0	0	0
Runella limosa	1.67	0	0	0	0
Thalassospira tepidiphila	1.64	0	0	0	0
Bacillus cereus	0	2.27	1.73	3.56	3.97

*Only major species are shown

Hangars 3 and 5

The line pigged at Hangars 3 and 5 is 6,500-feet long, 10-inch diameter ACP. The maximum water age ranges from 9.1 to 15.5 hours (Thomas/Wright Inc., 2014), and residual chlorine level post-pigging was 3.4 mg/L. The relative abundance data show that proteobacteria was predominant in all samples followed by cyanobacteria, actinobacteria, and firmicutes. Planctomycetes associated with the presence of algae were also found in all samples. Bacterial community composition at Hangars 3 and 5 appear to be quite different from the Ordnance Circle and Reeves bacterial community where the predominant organisms were firmicutes. The stacked bar chart showing the phyla is presented in Figure 20.

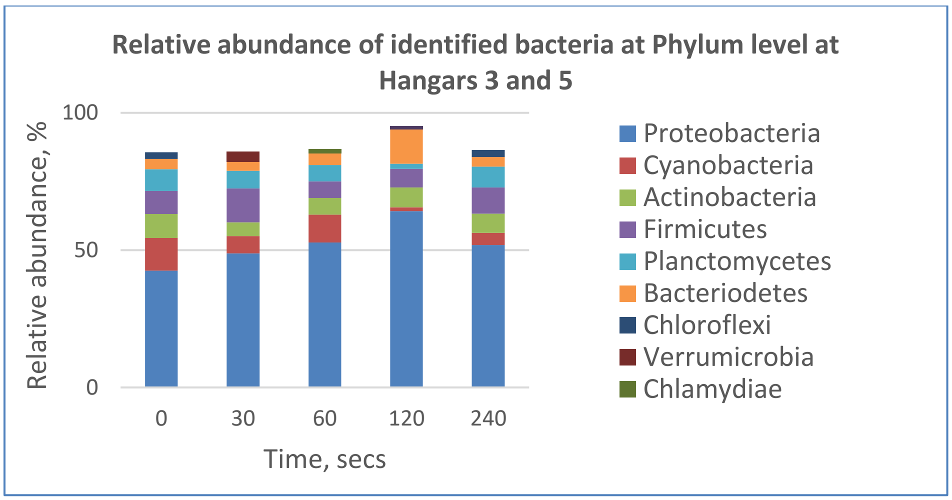

Figure 20. Relative Abundance of Identified Bacteria at Phylum Level at Hangars 3 and 5

The relative abundance in percent of bacteria at the species level is shown in Table 18. Cyanobacteria, *L. lminosa* and *C. parietina* had the highest total percentage of identified species. *Bifidobacterium bombi*, a gram-positive, non-spore forming anaerobe was found at the second highest level in the 0, 30 and 60 seconds samples and at the highest relative levels in the 240 seconds sample. *Pelamonas saccharophila*, a betaproteobacterium, was found to be present at the highest relative percentage in the 60 and 120 seconds samples. The bacterial composition in the Hangars 3 and 5 pipelines appears to be more diverse than the Ordnance Circle and Reeves pipelines.

Table 18. Relative abundance (%) of bacteria at the species level at different sampling times at Hangars 3 and 5*

	Sampling time, secs				
Classification	0	30	60	120	240
Leptolyngbia laminosa	7.3	2.29	2.76	0	3.55
Bifidobacterium bombi	6.37	2.92	3.53	0	3.73
Calothrix parietina	3.17	3.19	6.18	0	0
Escherichia albertii	2.02	0	0	0	0
Thalassospira tepidiphila	1.29	0	0	0	0.94
Serratia entomophila	1.17	0	0	0	0
Sphyngopyxis chilensis	1.1	2.39	3.2	1.47	3.13
Cohnella soli	0	4.1	0	0	0
Pelomonas saccharophila	0	1.28	9.74	16.05	2.28

*Only major species are shown

<u>Aircraft Park 1</u>

This pipeline consists of 1,020 feet of 14-inch ACP and 4,020 feet of 8-inch ACP. The maximum water age ranges from 11.2 to 20.7 hours. The chlorine residual was measured at 1.8 mg/L post ice pigging. The data for the phyla (Table 19) indicate that proteobacteria dominate the group at 42% to 53% for the 0 to 240 seconds samples. Proteobacteria appear to be distributed in a high proportion in the water-biofilm interface and throughout the biofilm. The most predominant groups in the 240 seconds sample are the proteobacteria followed by actinobacteria, and firmicutes. Bacteriodetes were the second most abundant in the 0 second sample, whereas firmicutes were the second most abundant in the 30 seconds sample.

The relative abundance of bacteria at the species level had only a small proportion of the reads (18% to 24%) categorized by the sequencing program. *Sphyngopyxis chilensis*, a chlorophenol degrading bacterium was found at 30 to 240 seconds samples indicating the potential presence chlorine disinfection byproducts. The cyanobacteria *Calothrix parietina* at substantial levels in the 30 to 240 seconds samples indicate the probable reaction of chlorine applied for disinfection with the cyanobacteria to produce chlorinated phenolic compounds.

Table 19. Relative abundance (%) of Bacteria at the Phylum Level at Aircraft Park 1

	Sampling time, secs				
Classification	0	30	60	120	240
Proteobacteria	51.15	42.19	41.84	53.16	42.38
Bacteriodetes	8.7	2.45	3.89	4.36	5.52
Firmicutes	8.4	22.34	11.72	9.8	14.9
Actinobacteria	0	3.62	14.52	8.95	16.2

*Only major phyla are shown

Hangar 2

This line is 2,200-feet long ACP of 16-inch diameter. The maximum water age ranged from 1.6 to 7.1 hours. No information is available on chlorine residual at this location. The data shown in and Figure 21 and Table 20 indicate that proteobacteria is the predominant group at all sampling times. Firmicutes form the second highest group, and this is followed by cyanobacteria. It is apparent that these groups of bacteria are present in all layers of the biofilm. Actinobacteria, commonly found in soil and water samples, and bacteriodetes are minor groups present in all samples.

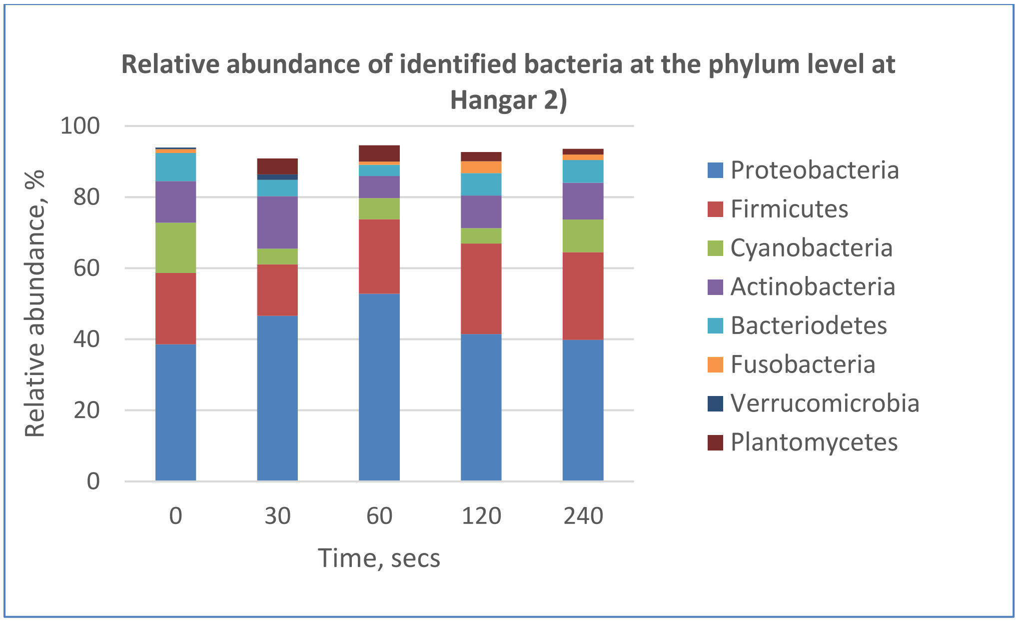

Figure 21. Relative Abundance of Identified Bacteria at the Phylum Level at Hangar 2

Table 20. Relative abundance (%) of bacteria at the species level at Hangar 2

	Sampling time, secs				
Classification	0	30	60	120	240
Calothrix parienta	11.74	0	4.02	1.78	6.7
Sphyngopyxis chilensis	2.68	2.59	3.78	3.53	2.82
Bacillus safensis	2.08	2.73	5.91	5.75	3.06
Bacillus mucilaginosus	1.73	2.07	3.75	4.43	3.98
Thioalkalivibrio jannaschii	0	6.84	10.29	4.72	3.06

*Only major species are shown

Conventional Hydraulic flushing

Conventional hydraulic flushing is commonly employed as a method to effect pipeline cleaning. However, contrary to popular belief, increase in flow velocity does not necessarily decrease biofilm growth rate unless the flow velocities are very high. Hydraulic shear can cause the removal of biofilm layers close to the water surface, but it may not be effective in detaching the biofilms closest to the pipe surface. As a result, the composition of bacteria released through hydraulic flushing may be quite different from that of ice pigging operations.

Two samples were obtained from an automatic flusher located near Hangar 5 at 60-second intervals from the start of the flush. The data are shown in and Figures 22 and 23.

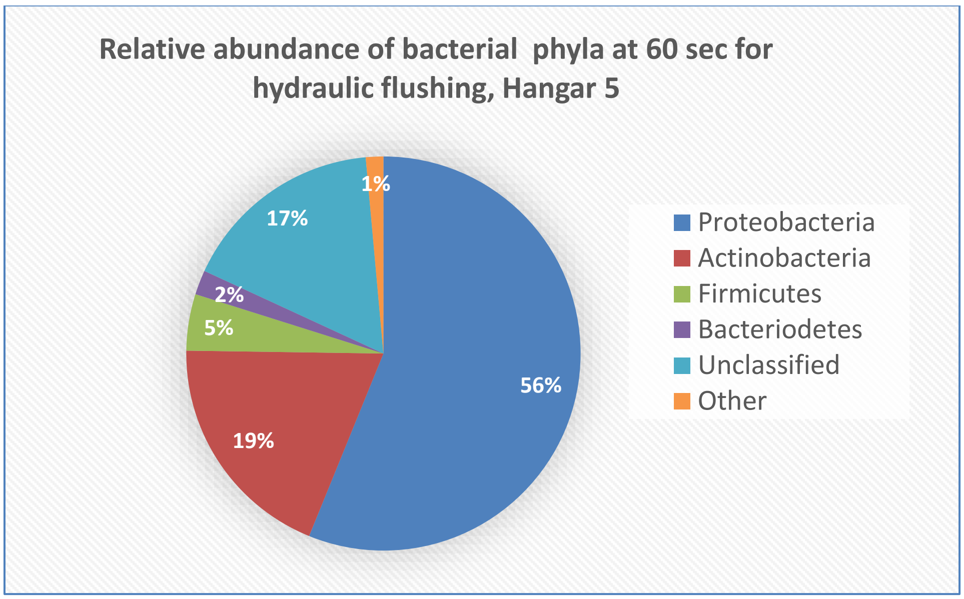

Figure 22. Relative Abundance of Bacteria Phyla at 60 Seconds for Hydraulic Flushing, Hangar 5

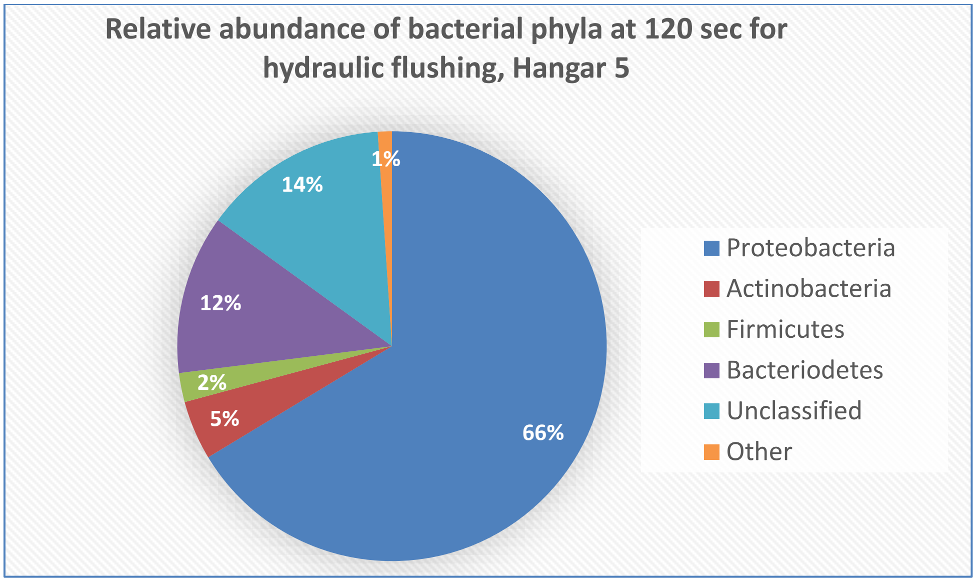

Figure 23. Relative Abundance of Bacteria Phyla at 120 seconds for Hydraulic Flushing, Hangar 5

The majority of the phyla is represented by proteobacteria at both the 60 and 120 seconds samples. The levels of proteobacteria increase from 60 to 120 seconds samples, whereas the levels for actinobacteria decrease. Unlike the ice pigging runs, the relative percentages of firmicutes are relatively low at ~ 2% in both cases. This indicates that automatic hydrant flushing does little in removing much of the bacilli biofilms. However, it does replace the stagnant zones with fresh water, thereby maintaining chlorine residuals at minimum required levels. Over a period of time, reaction of chlorine with the biofilm will result in the gradual depletion of chlorine residuals and cause an increase in TTHMs.

Summary

It was noted in Sec. 6.2.3.1, that biofilm and bacterial community structure are dependent on a number of structural factors and operating conditions such as disinfectant levels, nutrient availability, water age, etc. All of the five pipes tested for bacterial community profile were of ACP material, and the main variables were the disinfectant concentration levels, and the water age. Residual disinfectant levels ranged from 0.89 mg/L to 5.1 mg/L in the pipelines pigged. Disinfectant residual level is found to be a determinant of bacterial community structure in the pipeline. At very high disinfectant residual levels bacteria that are most resistant will dominate the community. In the case of Ordnance Circle and Reeves, bacilli from the firmicute phyla are the predominant bacteria. *Bacillus safensis*, *Bacillus mucillagiosus*, and *Bacillus cereus* were the predominant bacterial species. The free chlorine residuals in these pipelines were 3.2 mg/L. At less extreme disinfectant residual levels, bacteria belonging to proteobacteria phylum form the major group of bacteria in the biofilm. The pipelines at Hangar 3 and 5, Aircraft Park 1, and Hangar 2 had less extreme chlorine levels of 1.8 mg/L. Alphaproteobacteria, betaproteobacteria, and gammaproteobacteria where the predominant species in these pipelines.

Also, as noted in Sec. 6.2.3.1, that biofilms are formed in layers of groups of bacterial species depending on the nature of the bacteria (aerobic, anaerobic, facultative), and the ability to attach to the pipe surface. Aerobic bacteria can be expected to be closer to water-biofilm interface, whereas anaerobic bacteria that can adapt to the high pH pipe surface will be in the layer close to the pipe surface. The bacteria closest to the pipe surface are more tenuous due to the extracellular polymer matrix that forms the habitat. As the ice plug travels through the pipeline, it can be surmised that different layers of the biofilm will be removed as the plug passes through a given section, with the front end of the plug removing the outside biofilm layer, and the rear end removing the layer closest to the pipe wall. This is evident when examining bacterial community analyses of samples collected from 0 to 240 seconds during ice pigging.

In the case of Hangar 3 and 5 pipeline, and the Aircraft Park 1 pipeline, the firmicute level is much lower and eclipsed by the high levels of proteobacteria. This is in part due to the lower disinfectant levels. The hydraulic flushing sample showed the highest relative level of proteobacteria (66%) among all samples and the lowest amount of firmicutes at 2%. Each pipeline has a unique bacterial community structure with different groups of phyla making up the community in different pipelines. There is significantly higher species diversity in the ice pigging samples than the hydraulic flushing samples.

6.3 Residual Chlorine

Chlorine residual is an important measure of distribution system performance. The SDWA requires the maintenance of 0.2 mg/L free chlorine residual when chlorine is used as the disinfectant. Higher chlorine residuals may be required as sediments accumulate and biofilms proliferate in the distribution system. In pipelines with high water ages, chlorine will decay by reaction with organics and biofilms increasing the potential for coliform violations.

Biofilms and sediments in pipelines can cause increased chlorine demand due to the reaction of chlorine with inorganics in the sediment, and with the organic matter including TOC and biofilms (National Research Council, 1982; AWWARF, 2003). It is clear from Table 14, that considerable amount of inorganics such as iron and manganese were released along with TOC during ice pigging. In the case of conventional hydraulic flushing sediment and biofilm removal was much lower, and iron and manganese were not detected (Table 13). The removal of these materials and biofilms as discussed in Sec. 6.2.3 will result in reduced chlorine demand post ice pigging.

However, removal of sediment and biofilm by ice pigging by itself may not be sufficient to maintain adequate residual chlorine in the distribution system if the long water age is not reduced. A booster pump station was installed near Building 440 in the Weapons Area in December 2015. The purpose of the booster station is to circulate water through the OPS Area to reduce water age in the distribution system. Ice pigging was performed in May 2016, after the installation of the booster pump system. It is estimated that water age in the OPS Area was reduced from 39 hours to 23 hours through the implementation of booster pump system (Thomas/Wright, Inc. May 2014). The same study also calculated that water age in the WPNS Area was as high as 96 hours before implementation of booster pump station. Without booster pump to increase water circulation, this long water age is sufficient to deplete chlorine concentrations in the system even after ice pigging was performed.

Figure 24 shows the results of online residual chlorine monitoring data at the Weapons Area. We reduced the raw data from 60-second resolution to daily average to reduce cluster. Figure 25 shows results of the monthly residual chlorine grab sampling at Building 10, which is located upstream closer to the re-chlorination station, and Building 440 (Weapons Area), which is located in the far end of the distribution system.

Chlorine residual is typically lower in the far end of the distribution system. Chlorine residual by itself is not a good indicator of how well the system performs. Other factors, such as differences in residual between upstream and far end area, and intensity of flushing to maintain adequate residual in the system should be considered. Figures 24 and 25 show that chlorine residual post-ice pigging is not significantly different from the baseline and varies based on the chlorine set point in the incoming water. The average monthly residuals upstream (Building 10) and downstream (Weapons Area Building 440) post-ice pigging are 1.79 and 1.5 mg/L, respectively, which is within 16% difference. The data show that post-ice pigging the residual was adequately maintained with minimum hydrant flushing. The improvement can be attributed to both the recirculation in the dead-end area to reduce water age and ice pigging to clean the pipes.

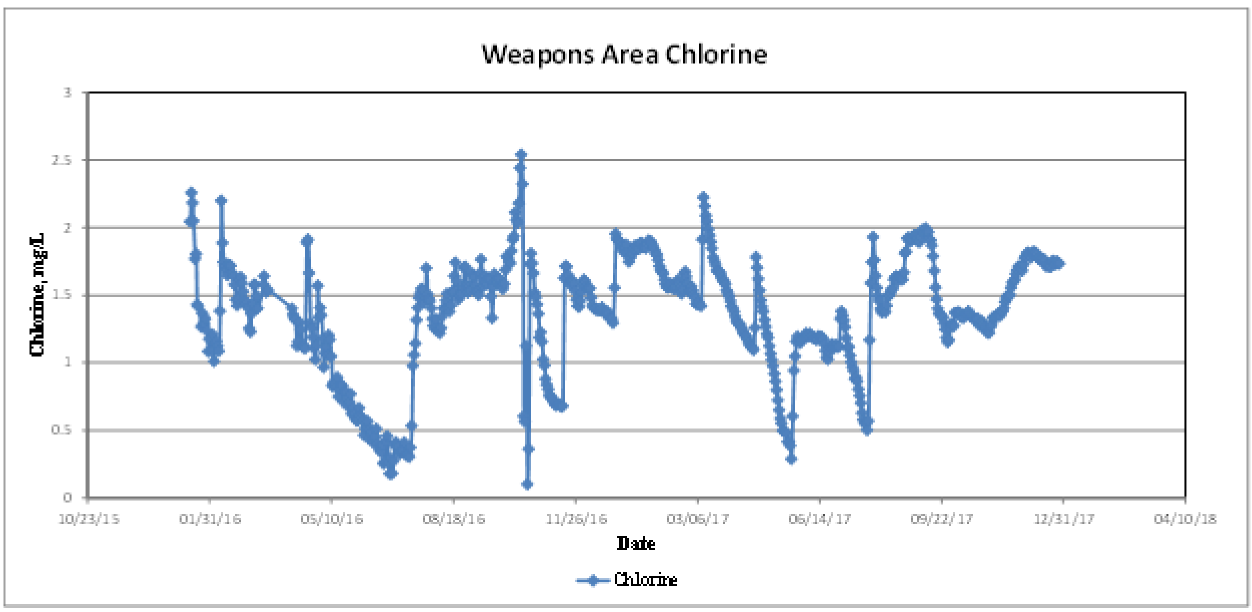

Figure 24. Daily average of chlorine residual in the Weapons Area.

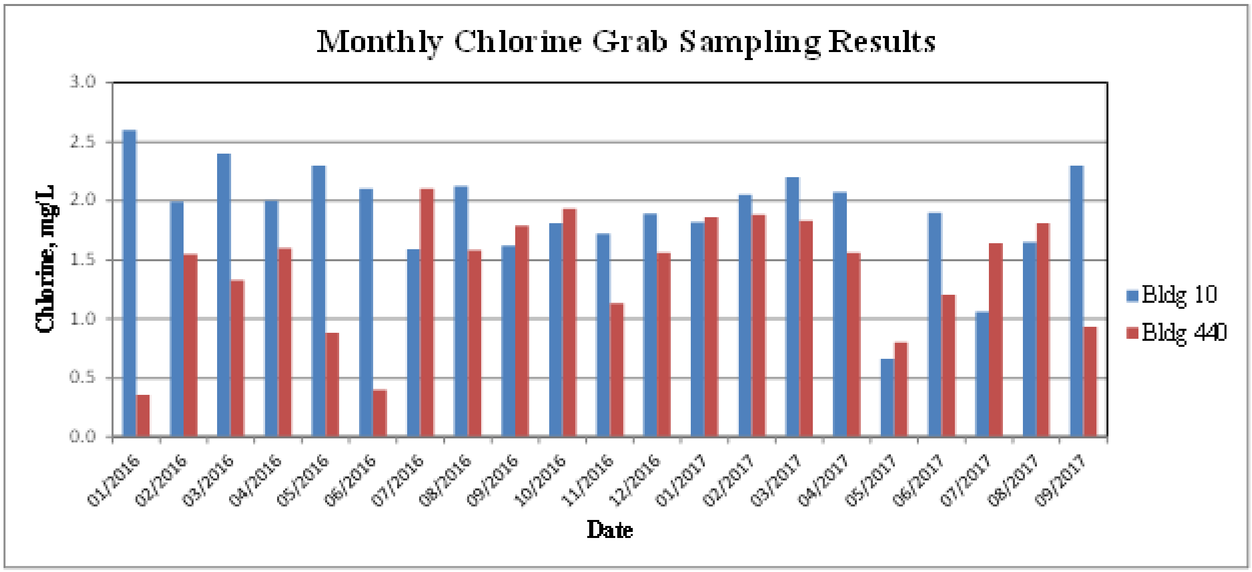

Figure 25. Monthly chlorine grab-sampling results.

6.4 TTHM Compliance

The presence of biofilms and TOC in pipelines results in the reaction of chlorine with these constituents and the production of disinfection byproducts (DBPs) such as TTHM and HAAC (Wang et al, 2013). Thus, the removal of biofilms can increase the chlorine residual levels, and reduce DBP production. Figure 26 shows the results of TTHM compliance monitoring. As shown in the figure, there were multiple MCL exceedances prior to ice pigging. After ice pigging, TTHM concentrations were consistently below 80 µg/L and compliance was achieved post-ice pigging. Ice pigging removed carbonaceous compounds including biofilms deposited on pipe walls that can react with chlorine in water to form TTHM and other DBPs.

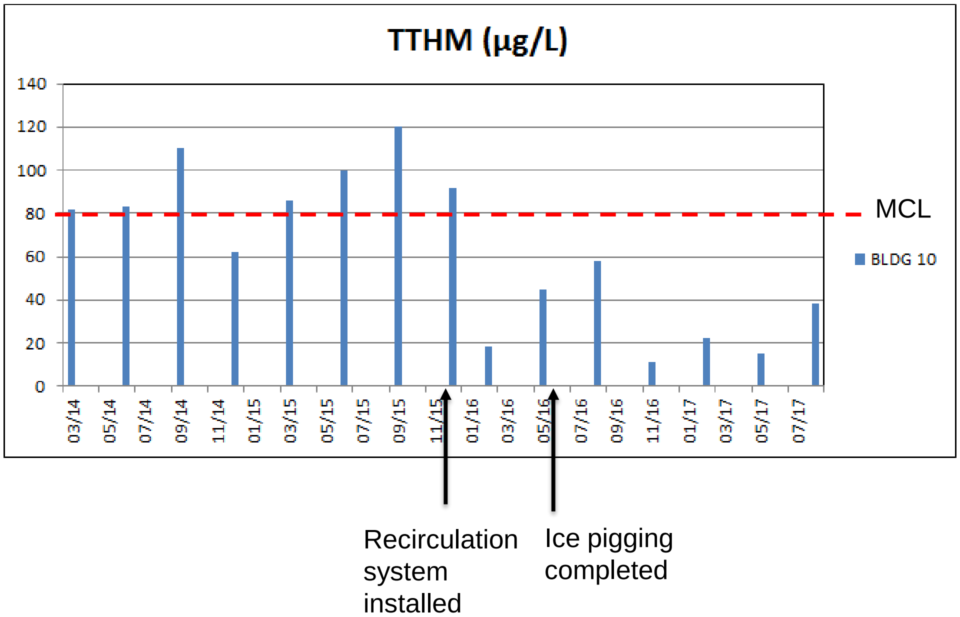

Figure 26. TTHM Compliance Monitoring Results

6.5 Turbidity

Turbidity levels in the distribution system is impacted by raw water quality, water treatment process, and by the release of accumulated sediments and biofilms into the water phase. Raw water quality of the surface water source varies to some extent with the seasons, particularly with respect to TOC levels. Since there have been no major changes in the water treatment process at NASL, the main cause of changing turbidity levels in the distribution system is likely due to the release of sediments and biofilms under different flow demand conditions. The data shown in Table 11 indicate that significant amounts of sediments were removed by ice pigging. Moreover, as discussed in Sec. 6.2.3, ice pigging has also resulted in the removal of biofilms. Thus, the turbidity levels can be expected to be lower post ice-pigging in the distribution system. However, turdibity results post-ice pigging were about the same, and not lower than the baseline level, as shown in Figure 27. The changes in turbidity levels are not discernable due to the low turbidity levels pre- and post-ice pigging. In both cases, turbidity changes from ~ 0.1 NTU in Winter to less than 0.3 NTU in Spring. It apparas that although sediments and biofilms were present on pipe walls prior to ice pigging, turbidity was low because no suspended solids were released into the water under those flow conditions.

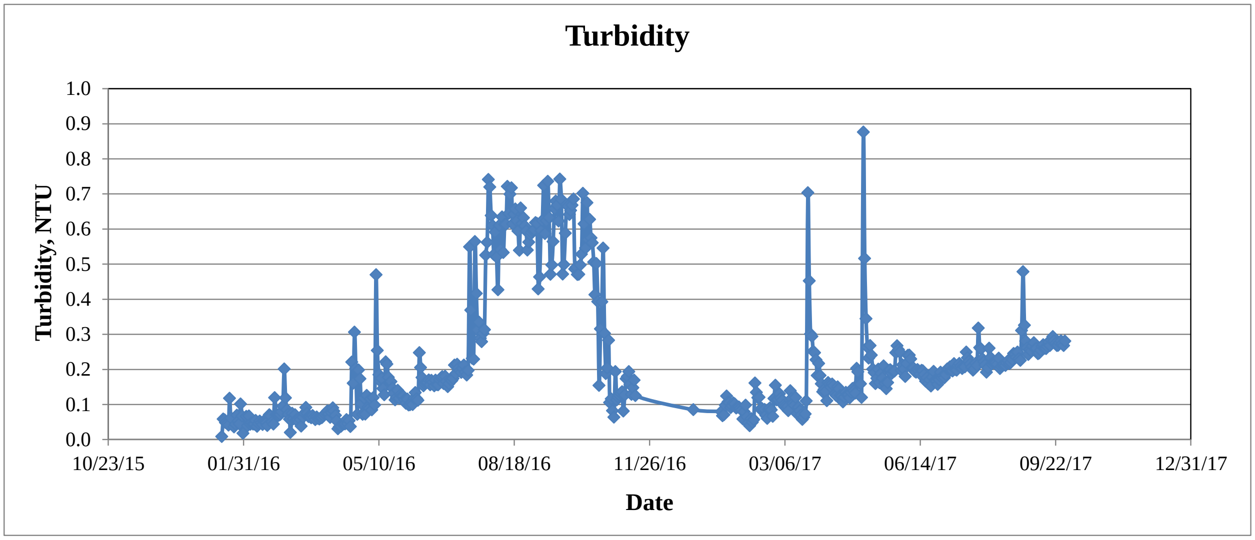

Figure 27. Turbidity levels in the Weapons Area distribution system

6.6 Chlorine Consumption Rate

The water treatment plant in the Administration Area supplies water to the OPS Area. Water is chlorinated in the plant and pumped into two 600,000-gallon storage tanks adjacent to Building 50 in the OPS Area via a 6-mile pipeline. These two storage tanks supply water to the OPS Area distribution system for both domestic and fire purposes. Prior to distribution in OPS Area, water in the tanks is typically re-chlorinated by a chlorine boosting station located in Building 50, due to low chlorine residuals in the storage tanks. The low chlorine residual was mainly caused by stagnant water in the tanks. Reducing dead zones in storage reservoirs can reduce chlorine demand and TTHM production (EPA, 2002).

In late 2016, operations of the two storage tanks in the OPS Area were modified to reduce the water age in the tanks. Plumbing was modified to add additional water pipes connecting between nearby hydrants and the storage tanks to form a recirculation loop. When OPS Area pump station is on, water is drawn from the tanks into the distribution system and at the same time pushing water from the hydrants into the tanks, thus displacing stagnant water in the tanks. Since the implementation of this tank recirculation system, re-chlorination in the OPS Area was essentially eliminated due to the ability to maintain adequate chlorine residual both within the tanks and distribution pipes.

Chlorine consumption for re-chlorination from January to September2016 was 521 gallons of sodium hypochlorite, based upon operation log Since October 2016, no sodium hypochlorite was used for re-chlorination. We estimated that the annual amount of sodium hypochlorite used for re-chlorination was 694.7 gallons per year prior to ice pigging. The amount of sodium hypochlorite used for re-chlorination post-ice pigging was 229.6 gallons/year, or a reduction of 465.1 gallons per year. The reduction in chlorine consumption cannot be attributed to ice pigging only since it cannot reduce water age in the tanks. However, ice pigging helps to reduce chlorine demand within distribution piping system and it appears that a combination of ice pigging and tank recirculation system resulted in the reduction of chlorine consumption rate for the re-chlorination.

6.7 System Economics

System economics are shown in Section 7. The calculated Savings to Investment Ratio (SIR) for ice pigging is 0.50. Because SIR is less than 1.0, ice pigging does not result in significant cost savings. However, it would be financially justifiable at a water rate of $0.008/gallon or higher.

6.8 Impact to Water System and Facility Operations

No issues or abnormality to water system or facility operation were noted during the entire period of ice pigging runs. Hangars are very critical with water stoppage and require water service no later than 08:00. For areas affecting Hangar operations, ice pigging was performed in early morning at 05:00 and completed by 07:30 to meet the water service requirements of the customers. Ice pigging run time is impacted by the time spent in locating upstream and downstream valves to isolate section of pipes for pigging. Typical ice pigging runs can be completed in 3 hours or less, unless there is difficulty in locating valves due to inaccurate utility drawings. Water supply downtime was below the performance objective of 4 hours.

6.9 User Satisfaction

Feedback from users was solicited via face-to-face conversations with operation and management personnel. Feedback from end user indicates positive feelings and satisfaction with respect to the deployment and operation of the ice pigging demonstration. There were challenges with scheduling for airfields where the ice pigging crew needed to leave the premise before 09:00 to avoid conflict with the airfield operations. Ice pigging at the hangar areas had to be completed before 07:00 because service water cannot be stopped beyond that time. Ice pigging runs were able to meet the scheduling challenges, and operations were performed without any issues with the water system operation. End user personnel present during ice pigging runs were satisfied with the amount of sediment removed as expressed through verbal comments. The project team did not hear any negative comments from the end user regarding the deployment and the ice pigging operations.

6.10 Consumer Satisfaction

The water treatment plant at NAS Lemoore provides domestic water to customers on the base. Complaints regarding water quality are directed to plant personnel. There were no complaints received during the baseline and post-ice pigging periods according to feedback received from plant operators. This is understandable because for the most part, water quality did not deteriorate visibly or taste wise to a level that could trigger customer complaints. Complaints, if any, are typically caused by water aesthetic issues, such as abnormal odor, color, or taste at the tap. Although there were TTHM violations the year before ice pigging, it did not result in abnormal appearances of the water to trigger complaints.

7.0 COST ASSESSMENT

This section discusses the costs associated with performing ice pigging and compares those costs with conventional hydrant flushing.

7.1 COST MODEL

A cost model is given in Table 21 that summarizes the cost elements associated with ice pigging performed in this demo.

Table 21. Cost Model for Ice Pigging at NASL

Cost Element	Quantity		Unit Cost	Total ($)
Ice pigging contract cost	55,845	ft	3.22	180,036
Contract fee, 2.3%	1	LS	4,141	4,141
SIOH, 6%	1	LS	10,802	10,802
Total ice pigging cost				194,979

Ice pigging contract cost is the cost to procure contract services for ice pigging. It includes direct labor and other direct costs. Direct labor includes labor costs for contractor to perform ice pigging, checking valves and hydrants, review analytical data, project coordination, and reporting. Other direct costs include waste tanker, valve and hydrant testing, sampling and analysis, mobilization and demobilization, and the costs for ice pigging runs, which are determined by the number of loads of ice. For the size of this project, the ice pigging contract cost is calculated to be $3.22 per linear feet (LF) of pipe or a total of $180,036 for 55,845 feet of pipe length.

Contract fee is the fee charged by Contracting Office and varies by contracting amounts and project locations. We estimate 2.3% of contract cost for this project.

Supervision, Inspection and Overhead (SIOH) is the cost for project oversight. Typical SIOH cost is 6% of contract amount.

Operator support is the costs of Government water system operators providing support to ice pigging runs, such as operating valves, shutting-off and restoring water services to affected area, and coordinating site access, etc. For the size of this project, operator support is estimated to be five persons for five hours per day of ice pigging run for twelve days of runs. Labor rate is estimated to be $44 per hour.

Total ice pigging cost is the sum total of the above cost elements. The cost model is based upon 12 loads of ice for pigging 55,845 feet of pipe length.

7.2 COST DRIVERS

The main cost drivers associated with ice pigging are the size (such as pipe diameters and lengths) of the water distribution system to be pigged, and complexity of the system (such as availability of insertion and extraction ports for ice pigging).

The size of distribution system required to be pigged in terms of linear feet of pipe length, and pipe diameters determine the number of loads of ice needed for the project. Each load consists of 2,700 gallon of ice slurry and requires a whole day for production on-site. The higher the number of loads for a particular project, the lower the unit cost of ice pigging. For example, ice pigging projects at NBVC Port Hueneme and NASL required 3 and 12 loads of ice, respectively, corresponding to unit costs of $8.08 and $5.56 per gallon of ice.

Long water mains that do not have access for insertion and extraction ports would incur additional costs to install appropriate ports. It is very rare that this would be required.

7.3 COST ANALYSIS AND COMPARISON

The project team performed a life-cycle cost analysis to compare the costs of distribution system operation with and without ice pigging. The study is based on a system having the size of the OPS Area in NASL.

The base case or control is the operation of three hydrant flushing systems without ice pigging. Capital cost for the base case includes installation of three hydrant flushing systems. Operational cost includes potable water lost due to flushing, chlorine consumption, and costs to maintain and operate hydraulic flushing and its data collection.

The ice pigging alternative involves performing ice pigging and reducing the need for hydrant flushing to a single flushing unit. Project team estimates that ice pigging is good for up to 7 years, and hydrant flushing system service life is 10 years. Major cost savings from ice pigging are due to reduction in potable water used for hydrant flushing, reduced chlorine consumption, and hydraulic flushing equipment maintenance and data analytics. Table 22 summarizes the calculated cost savings based upon data collected from this project.

Table 22. Estimated Cost Savings for Ice Pigging

Cost Element	Hydrant Flushing	Ice Pigging	Cost Savings
Water cost	$146,997	$62,434	$84,563
Recurring and Non-Recurring OM&R Costs	$38,034	$24,829	$13,204
Total Cost Saving:			$97,767

The project team performed life-cycle cost analysis to compare ice pigging with hydrant flushing. Base date is 1 October 2017 and project location is California. Study period is 7 years, from 1 October 2017 to 30 October 2023, corresponding to the estimated service life of ice pigging. Nominal discount rate used for the analysis is 2.4%, obtained from the published rate for 2017 and discount convention used is end-of-year. Annual cost escalation is assumed to be 1.2%. Residual values are assumed to be zero for both alternatives. Analysis was performed using the Building Life Cycle Cost Program, BLCC version 5.3-17 for Windows, developed by the National Institute of Standards and Technology (NIST).

Base Case: conventional hydrant flushing without ice pigging:

Initial capital requirements include costs for procurement and installation of three hydrant flushers, at an estimated cost of $5,000 each, or $15,000 total. Recurring and non-recurring annual operation, maintenance and repair (OM&R) costs include costs for chlorine consumption, operating flushers and their replacement. Chlorine consumption cost is estimated to be 520 gallons of sodium hypochlorite per year at $0.9 per gallon, based upon data collected from this project. The estimated labor required to operate three flushers is 80 hours per year, at a labor rate of $44.00/hour fully burdened rate, obtained from the Bureau of Labor Statistics for occupational class, Water and Wastewater Treatment Plant and System operators. Flusher replacement cost is calculated by annualizing the cost of three flushers over 10 years. Annual water lost due to hydrant flushing is 5,501,600 gallons per year at an average rate of $0.004 per gallon.

Alternative Case: ice pigging:

Initial capital requirements are cost for ice pigging services, procurement and installation of one hydrant flusher. Total ice pigging cost is $208,179, as shown by Table 21. Number of hydrant flusher needed is one at an estimated cost of $5,000. Recurring and non-recurring annual OM&R costs include costs for operating one flusher and its replacement. The estimated labor required to operate one flusher is 27 hours per year. Flusher replacement cost is calculated by annualizing the cost of one flusher over 10 years. Annual water lost due to hydrant flushing is 2,336,700 gallons per year at an average rate of $0.004 per gallon.

LCCA Results:

Table 23 shows LCCA results and the comparison of the Base Case and Alternative. As shown by the table, the present values (PV) for Base Case and Ice Pigging Alternative are $200,031 and $287,243, respectively. Calculated PV of net cost saving is -$87,212.

Saving to Investment Ratio (SIR) is the ratio of the PV of savings to the PV of the investment required to produce savings. Savings resulting from ice pigging is $97,767 in year 2017 dollar, as shown by Table 22. Investment cost for ice pigging is $194,979 in year 2017 dollar, as shown by Table 21. The SIR for ice pigging is calculated below.

$$SIR = \frac{PV\ Savings}{PV\ Investment}$$

$$SIR = \frac{\$97{,}767}{\$194{,}979} = 0.50$$

LCCA analysis shows that performing ice pigging does not result in a net cost saving. Although the water saving is significant, it does not translate into a net cost saving due to the current low water rates. Sensitivity analysis showed that ice pigging could have cost benefit when water rate is \$0.008 per gallon or higher. Table 24 shows comparison of costs if water rate is \$0.008 per gallon.

Ice pigging has other intangible benefits, such as proper maintenance of water distribution system, improved hydraulic capacity, and also it aids in water quality compliance that might offset the cost burden.

Table 23. Life-Cycle Cost Comparison for Hydrant Flushing and Ice Pigging

PV Life-Cycle Cost			
	Base Case (Hydrant Flushing)	**Alternative (Ice Pigging)**	**Savings from Alternative**
Initial Investment Costs Paid By Agency:			
Capital Requirements as of Base Date	$15,000	$194,979	($179,979)
Future Costs:			
Recurring and Non-Recurring Contract Costs	$0	$0	$0
Energy Consumption Costs	$0	$0	$0
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$146,997	$62,434	$84,563
Recurring and Non-Recurring OM&R Costs	$38,034	$24,829	$13,204
Capital Replacements	$0	$0	$0
Residual Value at End of Study Period	$0	$0	$0
	------------	------------	------------
Subtotal (for Future Cost Items)	$185,031	$87,264	$97,767
	------------	------------	------------
Total PV Life-Cycle Cost	$200,031	$282,243	($82,212)
Net Savings from Alternative Compared with Base Case			
PV of Operational Savings	$97,767		
- PV of Differential Costs	$179,979		

Net Savings	($82,212)		

Table 24. Life-Cycle Cost Comparison for Hydrant Flushing and Ice Pigging at Water Rate 0.008/gal

PV Life-Cycle Cost			
	Base Case (Hydrant Flushing)	Alternative (Ice Pigging)	Savings from Alternative
Initial Investment Costs Paid By Agency:			
Capital Requirements as of Base Date	$15,000	$194,979	($179,979)
Future Costs:			
Recurring and Non-Recurring Contract Costs	$0	$0	$0
Energy Consumption Costs	$0	$0	$0
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$293,994	$124,868	$169,125
Recurring and Non-Recurring OM&R Costs	$38,034	$24,829	$13,204
Capital Replacements	$0	$0	$0
Residual Value at End of Study Period	$0	$0	$0
	------------	------------	------------
Subtotal (for Future Cost Items)	$332,027	$149,698	$182,330
	------------	------------	------------
Total PV Life-Cycle Cost	$347,027	$344,677	$2,351
Net Savings from Alternative Compared with Base Case			
PV of Operational Savings	$182,330		
- PV of Differential Costs	$179,979		

Net Savings	$2,351		

8.0 IMPLEMENTATION ISSUES

8.1 TECHNOLOGY IMPLEMENTATION

Ice pigging technology has been commercialized and SUEZ is the sole licensee of the technology who can perform the ice pigging. Implementation is typically achieved through standard contracts to procure ice pigging services.

Pre-ice pigging planning is critical for project success. Prior to initiating contract, pre-ice pigging planning should be performed. SUEZ's regional rep typically goes on-site to attend pre-planning meeting and assist with project planning. As-built drawings of water distribution system should be made available for planning ice pigging runs.

8.2 LESSONS LEARNED

- Ice pigging is an effective water main cleaning technique. However, it cleans the water main only, and cannot increase water demands that will allow water ages to decrease within the distribution system. Therefore, ice pigging may not resolve issues associated with long water age, although it may help in the short term by removing sediments and biofilm that cause chlorine consumption. Installations having water quality issues caused by long water age should seek solutions to reduce water age. Water main cleaning improves system operations when water age is under control.

- Ice pigging would be financially justifiable at a water rate of $0.008/gallon or higher due to significant water savings from reduced demand for hydrant flushing.

- Water service disruption could be very problematic for DoD facilities performing critical missions. It is difficult to communicate water stoppage schedules to all affected facilities. Project planning should include adequate coordination with affected facilities to work out acceptable water stoppage schedules. Ice pigging operations can be completed within three hours if preparation is adequate and there are no abnormal problems in the field affecting implementation. Thus, with proper coordination, water stoppage can be scheduled for early morning hours before normal business hours such that water service can be restored during business hours. It can also be scheduled during weekends to minimize impact to facilities performing critical missions.

- Ice pigging requires support from the water distribution system operators to perform tasks such as operating valves for ice pigging operations, shutting off and turning on water supplies to affected facilities, coordinating with facility access, locating valves, etc. Planning should account for the availability of needed resources to support ice pigging.

- For instances where valves cannot be located due to inaccurate drawings, a metal detector is very helpful for locating valves and other appurtenances.

- The risk of damage to water pipes is very low since ice pigging uses water systems' own water pressure for pigging. A water distribution system planned for ice pigging should be in fair operating condition. Water mains meeting requirements for normal water distribution system operations are suitable for ice pigging.

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Wang, D., R. Cullimore, Y. Hu, and R.Chowdhury, Biodeterioration of asbestos cement (AC) pipe in drinking water distribution systems, *International Biodeterioration and Biodegradation*, 65, 810-817, 2011.

Wang, J.J, X. Liu, T.W. Ng, J.W., Xiao, A.T. Chow, and P.K. Wong, Disinfection byproduct formation from chlorination of pure bacterial cells and pipeline biofilms, *Water Research*, 47 2701-2709, 2013.

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Appendix A: Points of Contact

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Table A1. Points of Contact

Performers	Organization	Phone	Email	Role
Steven Fann	NAVFAC EXWC	805-982-1016	steve.fann@navy.mil	PI
Casey Barker	NAVFAC EXWC	805-982-1478	casey.barker@navy.mil	Tech Integration
Brian Kyle	NAS Lemoore	559-998-1074	brian.kyle@navy.mil	UEM Support
Louis Carnevale	EURAFSWA	39-081-568-1012	louis.carnevale@eu.navy.mil	Tech Transition
Mark Ginsburg	ERDC	217-373-6754	Mark.D.Ginsberg@usace.army.mil	Army Tech Transition
Dawn Halpern	SUEZ	619-818-3840	DHalpern@UtilityService.com	Contractor
Paul Treloar	SUEZ	478-244-4303	PTreloar@UtilityService.com	Contractor
Dr. Alex Mathews	National Resources Consultants	785-341-6175	matsci2001@yahoo.com	Technical Consultant

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Appendix B: Response to Action Items and Review Comments

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Response to Action Items

1. In the Final Report, please cite the reference sources for the time periods required to service the different types of pipe.

   Response: The cleaning frequency would be impacted by a number of factors including water source and quality, water age in the pipeline, and pipe material. Biofilm formation is enhanced by the presence of TOC and nutrients in the water, and to some extent by pipe surfaces that are more conducive to bacterial attachment. Studies have shown that cast iron pipes harbor a higher diversity of bacterial biofilm communities, while PVC pipes display low bacterial attachment and biofilm formation (Yu et al, 2010; Jang et al, 2011; Ren et al, 2015).

   The cleaning frequency would be site specific depending on the above factors and local operating procedures including the disinfectant type and amount used, and flow velocities in the lines. There has been no request to date from customers wishing to repeat the process on ice pigged lines over the last six years. Based on the history of ice pigging operations, it is reasonable to assume that the time period required to repeat the service is likely to be close to seven years.

   Jang, H-J, Y-J Choi, and J-Ok Ka, Effects of diverse water pipe materials on bacterial communities and water quality in the annular reactor, J. Microbiol. Biotechnol., 21, 115-123, 2011.

   Ren, H., W. Wang, Y. Liu, S. Liu, L. Lou, D. Cheng, X. He, X. Zhou, S. Qiu, L. Fu, J. Liu, and B.Hu, Pyrosequencing analysis of bacterial communities in biofilms from different pipe materials in a city drinking water distribution system in China, Appl. Microbiol. Biotechnol., 99, 10713-10724, 2015.

   Yu, J., D. Kim, and T. Lee, Microbial diversity in biofilms on water distribution pipes of different materials, Water Science and Technology, 61.1, 163-171, 2010.

2. In your Final Report, please make sure to address the following: Assess the limitations of ice pigging based on pipe diameter, length, and other significant factors, and Calculate return on investment compared to routine flushing frequency and cost.

   Response: Ice pigging is limited by the amount of ice slurry available for pigging. Typical ice pigging is performed with one ice delivery truck having capacity of 2,700 gallons of ice. Current limitation with one ice delivery truck is 24-inch diameter pipes having pipe lengths listed below:

   Cast iron (CI): 750 LF
   Ductile iron (DI): 1,500 LF
   PVC/HDPE/AC: 2,300 LF

   Larger diameter of pipes can be pigged with two ice delivery trucks if the sites are accessible.

Return on investment calculations are provided in Section 7.3.

3. In the Final Report, include test data which shows the amount of bacteria reduced due to ice pigging.

   Response: Bacterial sampling data and results of analysis are included in Sections 6.2.2 and 6.2.3 of the report.

Response to Review Comments:

Final Report Version 1 Comments

Executive Summary
The discussion of bacterial community analysis is fascinating, but as written it is far too technical for the executive summary. I think the key point of the analysis was to show ice pigging was more effective at removing entrenched microbes, while traditional hydraulic flushing only removed some at the surface of the biofilm. Readers of the executive summary need to know what effect that has on long-term potable water quality and operational effectiveness. The rest of the details regarding phylum and species is better suited for the body of the report.

Response: Revised bacterial community analysis paragraph to shorten the discussion.

Executive Summary
In the paragraph that discusses improvements to operations, each factor should be explained as a comparison between ice pigging and hydraulic flushing. You could even include a table to make the comparison easier to read. Water use and chlorine consumption are compared well. Sediment and disinfection by-products (TTHM) are not compared at all. For example, if you have the data you could say "ice pigging removed xx lbs of sediment per mile of pipe compared to yy lbs per mile for hydraulic flushing". You say TTHM levels were well below MCL, but what were they for hydraulic flushing?

Response: Revised the paragraph and included a table for comparison of improvement between ice pigging and hydraulic flushing.

Executive Summary last paragraph
I would recommend revising the last paragraph of the executive summary to explain how sensitive the business case is to changes in the cost of water. Also discuss what metrics system owners should watch to determine whether or not they need ice pigging. As a former Air Force Base Civil Engineer, I think this technology is fantastic, and I would have loved to implement it on my ancient water system. So I'm very interested in shoring up the business case in order to improve uptake from the facilities community. System owners need to know where the thresholds are (i.e. under what circumstances would this be a good investment? and when would it be a bad one?)

Response: Added a paragraph to discuss when ice pigging is needed.

1.2
Table 1 compares water cleaning techniques, but Section 1.2 should be clear which two techniques are being compared in this demonstration. I think you are comparing ice pigging with what is called "conventional flushing" in Table 1. Later in the document, you refer to "hydraulic flushing". Please be consistent with terms (i.e. "conventional hydraulic flushing") to avoid confusing the reader.

Response: Revised to be more consistent with the term "conventional hydraulic flushing."

2.0
This section describing advantages and limitations is rather chaotic. A reader may be trying to compare ice pigging to the technique he or she uses locally. Some of the comparisons in this section will apply, but others will not, and it is not immediately obvious to the reader which is which. To

clarify for the reader, consider organizing the advantages and disadvantages by the technique being compared. To keep from repeating yourself too often, you could combine similar techniques. For example, how does ice pigging compare to conventional flushing and uni-directional flushing? How does it compare to swabbing, pigging, and mechanical cleaning?
Response: Revised to include comparison between ice pigging, conventional flushing, UDF, and swabbing, pigging, and mechanical cleaning.

3.0
Again, the question was not answered. Success criteria was "number of consumer complaints after ice pigging less than the number before", but the result statement simply says, "no post-pigging complaints noted". What efforts were made to solicit comments before and after pigging? Were any comments received before pigging? If there were no comments before, and none after, simply because no one solicited feedback, can we really call that success?

Response: Section 3.0 in the previous version was changed to Section 3.2.10 to correct the numbering. Consumer complaints are more likely to be received when the supplied water has taste and/or odor problems, or if the water is discolored from sediments or corrosion products. Since there are no CI or steel pipes in the system, there is less likelihood of color due to oxides or sediment being released in significant quantities to elicit consumer complaints. TTHM violations are less likely to elicit responses from consumers due to the lack of sensory cues. Plant records indicate there were no complaints prior to and post ice pigging.

3.2.3
Measurement of chlorine residual alone is insufficient to measure cleaning effectiveness without some measure of how much effort it takes to maintain that level. How does the post-ice pigging residual compare with the baseline? and how much chlorine was used after ice pigging compared to the baseline period?

Response: Chlorine residual tends to decay in the far end of a distribution system where water is more stagnant. Conventional hydraulic flushing is typically performed to restore residuals in the dead-end areas. If the pipes are clean and water age is not too high, residual should be slightly lower in the dead-end areas with normal flushing. If water is more stagnant and pipes are not clean, residual would decay faster due to higher chlorine demand and would require more aggressive flushing to maintain the residual above the minimum required level. Thus, residual is impacted by water age, flushing frequency and volume, and biofilms on the pipe walls.

Installation of a recirculation system by NAS Lemoore in Dec 2015 makes the determination of the impact of ice pigging difficult. Residual chlorine post-ice pigging is similar to that of the baseline and both are way above 0.3 mg/L. Since we started monitoring residual in January 2016, the baseline residual reflects the conditions with the recirculation system. The data show that adequate residual was maintained during the period after installation of the recirculation system and prior to ice pigging. After ice pigging, adequate residual was also maintained, except for a brief period when the recirculation system was off.

The demonstration shows that ice pigging by itself cannot maintain adequate residual if water age is high. It also shows that residual is good when both water mains have been cleaned by ice pigging and water age is under control. It would be interesting to see if satisfactory levels of chlorine residual are m maintained when only water age is reduced (by the recirculation system) but the pipes are not cleaned. Unfortunately, we do not have the data to show that effect due to the timing of the demonstration.

Chlorine used for re-chlorination also did not change significantly post-ice pigging. However, re-chlorination was virtually eliminated after September 2016 when a recirculation system was installed to recirculate water from distribution system back to the storage tanks at the re-chlorination station at Building 50. Chlorine consumption rate is affected more by the water quality in storage tanks than the conditions downstream. Thus, ice pigging did not result in a meaningful reduction of chlorine consumption. It is the improved mixing in the tanks that has resulted in significant reduction in chlorine consumption.

3.2.4
Comparing TTHM concentrations to the MCL is insufficient to determine effectiveness of ice pigging compared to conventional flushing. What were TTHM concentrations during the baseline period?

Response: TTHM concentrations the year prior to ice pigging exceeded the MCL of 80 ug/L four times. After ice pigging, there was no exceedance. Paragraph was revised for clarification.

3.2.5
Success criteria was to reduce turbidity by 15% or more compared with conventional hydraulic flushing. The results say "turbidity decreased to <0.3 NTU". Please provide a comparison to baseline turbidity and explain whether the reduction was 15% or greater.

Response: Result was changed to "no significant change before and after ice pigging". The daily average turbidity data show that post ice pigging turbidity did not change significantly from the baseline. During period from July to September 2016, turbidity was higher. This might be due to water being stirred up when recirculation was turned back on in July. Turbidity was below 0.3 NTU for the most part, which is quite low. Although sediments were present on pipe walls prior to ice pigging, turbidity was low because no suspended solids were released into the water.

3.2.6
Installation of the recirculation system by system operators in Dec 2015 makes the impact of ice pigging unclear. Does the installation have historical data on chlorine consumption prior to the recirculating system? And were you able to collect baseline measurements after the recirculation system was installed and prior to ice pigging? You show data on water usage during flushing each month from June 2015 to May 2016 (Table 9). Were no data collected on chlorine residual during that period? If you have those three data points (including post-pigging results), you should be able separate the effect of the recirculating system from that due to ice pigging.

Response: Water entering the OPS Area is pre-chlorinated and stored in two 60,000-gallon tanks. The water is re-chlorinated prior to entering the distribution system when residuals in the tanks are low. Chlorine consumption rate for the re-chlorination is determined mainly by the chlorine demand at the point of entry and is not impacted by ice pigging downstream. Thus, chlorine consumption rate is not a good indicator of the ice pigging performance. Although the demonstration shows that chlorine consumption rate was reduced more than 15% post-ice pigging, the reduction was attributed to the installation of a recirculation system in the OPS Area storage tanks after ice pigging. The installed system improves mixing in the tanks that eliminates or reduces the loss of residual due to water stagnation in the tanks. When residuals in the tanks are adequate, it is not needed to boost the chlorine when pumping into the distribution system.

3.2.9
The result statement does not really answer the question. The success criteria were "positive feedback from users", but the results statement discusses system modifications. What feedback was received from users? Was any solicited?

Response
Informal data from the end user operations and management personnel indicate positive feelings and satisfaction with respect to the deployment and operation of the ice pigging demonstration. End user is satisfied with the amount of sediment removed the pipelines.

Feedback from users was solicited via face-to-face conversations with operation and management personnel. Feedback from end user indicates positive feelings and satisfaction with respect to the deployment and operation of the ice pigging demonstration. There were challenges with scheduling for airfields where the ice pigging crew needed to leave the premise before 09:00 to avoid conflict with the airfield operations. Ice pigging at the hangar area had to complete before 07:00 because service water cannot be stopped beyond that time. Ice pigging were able to meet the scheduling challenges and operations were performed without any issues with the water system. End users present during ice pigging runs were satisfied with the amount of sediment removed through verbal comments. Project team did not hear any negative comments from the end users regarding the deployment and operation of the ice pigging.

4.2
This section states that site personnel were eager to reduce water wasted in flushing operations and that the area is prone to water scarcity. How did site personnel feel about pigging after the demonstration? Will ice pigging resolve water scarcity issues? It would be beneficial to discuss those things in the conclusion

Response: Water is a critical but unpredictable natural resource that must be managed sustainably. Droughts can occur at any of the Navy bases, but the severity of the impacts will depend on the duration and number of successive events. California suffered through two droughts in the last eight years that required the implementation of conservation measures, and the elimination of wastage. Ice pigging of pipelines, and the resultant reduction in water lost through flushing operations is an important part of a multifaceted approach to address water scarcity issues. The NASL facility operators are pleased with the fact, ice pigging allows proper maintenance of water quality while conserving water and reducing the cost of water production.
Report was revised to incorporate the above discussions in the conclusion.

5.0 and 5.1
Why are the demonstration question and the hypothesis different? The demonstration question talks about cost effectiveness and reducing water consumption, but the hypothesis talks about cleaning

effectiveness. The concepts may be linked, but you need to be clearer about how. Otherwise, you leave the reader confused about the overall objective of the study.

Response: Demonstration question has been re-worded in the report.

Demonstration question: The main question to be answered with this demonstration is whether ice pigging technology can be used as a periodic maintenance tool to cost-effectively clean the water distribution system to maintain water quality, and thereby minimize water wastage through hydrant flushing operations.

Hypothesis has been changed to link the demonstration question in the report.

Hypothesis: Ice pigging can effectively clean potable water distribution systems and thereby assist in the maintenance of proper disinfectant residual levels without the need for excessive hydrant flushing as currently practiced.

Table 5
Please provide a map (or maps) to accompany this table depicting locations of the various pigged lines as well as insertion and sampling points. When I got to Section 6.2.2 and read about flushing samples taken at "Hangar 5" and pigging samples taken at various other locations I was left wondering where those points were in relation to one another and I could find no map to help me.

Response: A color coded map of ice pigging runs was added to the report. We also added maps of daily ice pigging runs in appendix. Map of sampling locations is provided by Figure 15 under Section 5.5.5.

Table 9
Table 9 compares the amount of water used per month in the baseline period and after ice pigging. Although the total water usage for the year was reduced 57%, there were two months at the end of the demonstration period when post-ice pigging values exceeded baseline values. Please explain why that happened.
Also, what is the story behind why the baseline figures vary widely over the year, while post-ice pigging values remain consistent?

Response: Although the total water usage for the year was reduced, there were two months (April and May) at the end of the demonstration period when post-ice pigging values exceeded the baseline values. The reason for that was the water service to part of the distribution system (Hangar No. 5 area) was shutoff during April and May in 2016 due to construction activities. The automatic flusher in that area was also shutoff, resulting in lower water consumption for those two months. The water service and flusher were put back in service in June 2016.

The baseline water consumption numbers vary widely over the year likely due to the unsteady system performance during that period. Water flushers automatically adjusted the duration of flushing corresponding to the residual levels. Operators also adjusted the frequencies of the flushers responding to the levels of residual in the dead-end areas. The fluctuation of the water consumption numbers reflects the difficulty in maintaining adequate residuals.

During post-ice pigging period, system performance was steadier. Operators reduced the flushing schedules gradually after seeing improvement in both residual and TTHM.

Figures 21 and 22
It is unclear why the chart type was changed to a pie graph after all of the pigging results were shown as bar charts. Please use a consistent chart type to make comparison easier.

Response:
Pie charts are easier to read if the number of species items is not too high. They were used due to the lower number of species in the water from hydrant flushing, and to better illustrate the abundance of proteobacteria relative to firmicutes in these samples.

6.2.3.3 Summary
The Bacterial Community Analysis section is filled with volumes of interesting data, but in the summary, I am left wondering "what was the point?" After analyzing all the data about bacterial communities before pigging and after, what conclusions can we draw about the effectiveness or benefits of ice pigging?

Response: Additional conclusions have been added to the report.

Bacterial community analysis study was limited in scope. Samples were collected only from five of the 14 pigged lines. However, based on the available data, it can be seen that there is a difference in the bacterial community profiles between pipelines with high chlorine residuals compared to the ones with lower residuals. The former had more resistant bacteria such as bacilli from the firmicute phylum. The latter pipelines had more proteobacteria than firmicutes, and species diversity was higher in this group. Conventional flushing removes mainly bacteria at the water-biofilm interface due to the low shear at conventional flushing velocities. At the same disinfectant level, species distribution from conventional flushing is different from that of ice pigging.

6.2.2 Page 40
In this section you make the statement that, "hydraulic flushing showed no bacterial counts [indicating] the inability of hydrant flushing to remove biofilms..." However, Figures 21 and 22 appear to contradict this statement by showing bacterial counts for hydraulic flushing at Hangar 5 at 60 and 120 second intervals. Please explain this apparent contradiction.

Response:
This conclusion is based on the data in Tables 11 to 13. The hydraulic flushing samples show no HPC, whereas 10 out of 13 of the ice-pigged samples show positive values for HPC. Bacterial community analyses using 16S rRNA sequencing shows only the relative abundance of different bacterial species, not the absolute numbers. Hydraulic flushing will remove lose bacteria at the water-biofilm interface, but not the entrenched bacteria close to the pipe interior surface.

Figure 23
You show the steady increase of chlorine residual over time, but residual alone is insufficient to conclusively show the effectiveness of ice pigging. For example, the same effect can be achieved by simply injecting more chlorine into the system. Please include a graph showing the amount of

chlorine injected. If residual is trending up while injection is flat or decreasing, you have conclusive proof the pipes are cleaner.

Response: We replaced the 60-second resolution chart in Figure 23 with a daily average chart to reduce cluster. We also added a monthly chlorine grab sampling result chart. We revised the assessment of chlorine residual to show that improvement to system performance is due to the ability to maintain adequate residual in the far end of the distribution system with minimum flushing. Improvement was attributed to both water age reduction and ice pigging. Ice pigging by itself could not result maintenance of adequate residual without aggressive flushing if water age is long.

6.9 and 6.10
User satisfaction and customer satisfaction are not adequately explained. Please explain what was done to solicit feedback from the two groups. How did these two groups feel about their water system and water quality before ice-pigging, and how did their attitudes change (or stay the same) after the demonstration?
Section 6.9 simply discusses the lack of system modifications required to conduct ice pigging, but says nothing about system operator reaction to the demonstration. How did their attitudes change from before ice pigging to after?
Similarly, Section 6.10 says not complaints were received. If customers were dissatisfied, it is unlikely they would contact a contractor directly. What was done by the team to solicit customer feedback?

Response: Section 6.9 and 6.10 were revised to clarify assessment of User and Customer Satisfaction.

7.3
Did the team perform any sensitivity analysis for this cost comparison? The return on investment seems highly dependent on the cost of water. Would ice pigging make more sense in an area where water cost more than $0.004/gal? What is the break point? This information will be important when trying to encourage broader implementation of this technique.

Response: A sensitivity analysis was performed and included in the report. The results show that ice pigging could have a cost benefit when the cost of water is equal or greater than $0.008 per gallon.

Final Report Version 2 Comments

Overall: This is a much improved product. All comments from previous version have been addressed.

Response: We appreciate the positive feedback.

Executive Summary: Per the new guidance, please revise the executive summary section to include a 5 to 10 page extended Executive Summary. The Executive Summary will be posted as a stand-alone document on the SERDP & ESTCP web site. It should include key graphics and tables from the Final Report. Include the following sections: • Introduction; • Objectives; • Technology Description; • Performance Assessment; • Cost Assessment; • Implementation Issues

Response: The Executive Summary was revised to a 7-page extended Executive Summary.

3.2.7: The last sentence says, "Although the water saving is significant, due to the current low water rates, this does translate into net cost saving". I think you meant to say, "...this does not translate into net cost savings."

Response: The sentence was revised for correction.

Final Report Version 3 Comments

(1) Table 3. Performance Objectives: The results need to be more clearly stated. They should be either met, not met, or not applicable. You can explain in more detail in the section below. This table ought to be very easy to understand at first glance.

For example, Residual Chlorine should simply have "N/A" in the results block. You can explain in the section below that you were unable to separate the influence of the re-circulation system from the influence of the ice pigging.

TTHM should simply say, "Met"

Customer Satisfaction should be "N/A" because no baseline measurements were taken

Response: Table 3 was revised to show results as Met, Not Met, or N/A.

(2) Table 3 and Section 6.5: Results for turbidity are confusing. The statement in the results table seem to indicate the turbidity performance did not meet your objective because there was "no significant change" when the objective was ">15% reduction".

However, section 6.5 seems to state that the objective of reduced turbidity was clearly met: "This is illustrated in Figure 27, where a steady decrease in turbidity levels from pre- to post ice pigging."

So, which result is correct? Was there a 15% decrease in turbidity? or was there not?

Response: Turbidity results were revised to Not Met because there was no measurable changes in turbidity post-ice pigging due to the low readings. Turbidity values were less than 0.3 NTU pre- and post-ice pigging. Both Table 3 and Section 6.5 were revised to reflect this change.

(3) Overall: The major point is that this technology is financially justifiable at $0.008/gal. Unfortunately, that point is buried deep in the middle of the Exec Summary and deep in the economic analysis section of the report body.

I would suggest making the point much more boldly. Don't let the discussion of technical details obscure it.

Response: We added the financial case and incentive for ice pigging as water rates go up, in the Executive Summary (under Performance Assessment), Sections 3.2.7, 6.7, and 8.2.

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Appendix C: Maps of Ice Pigging Runs

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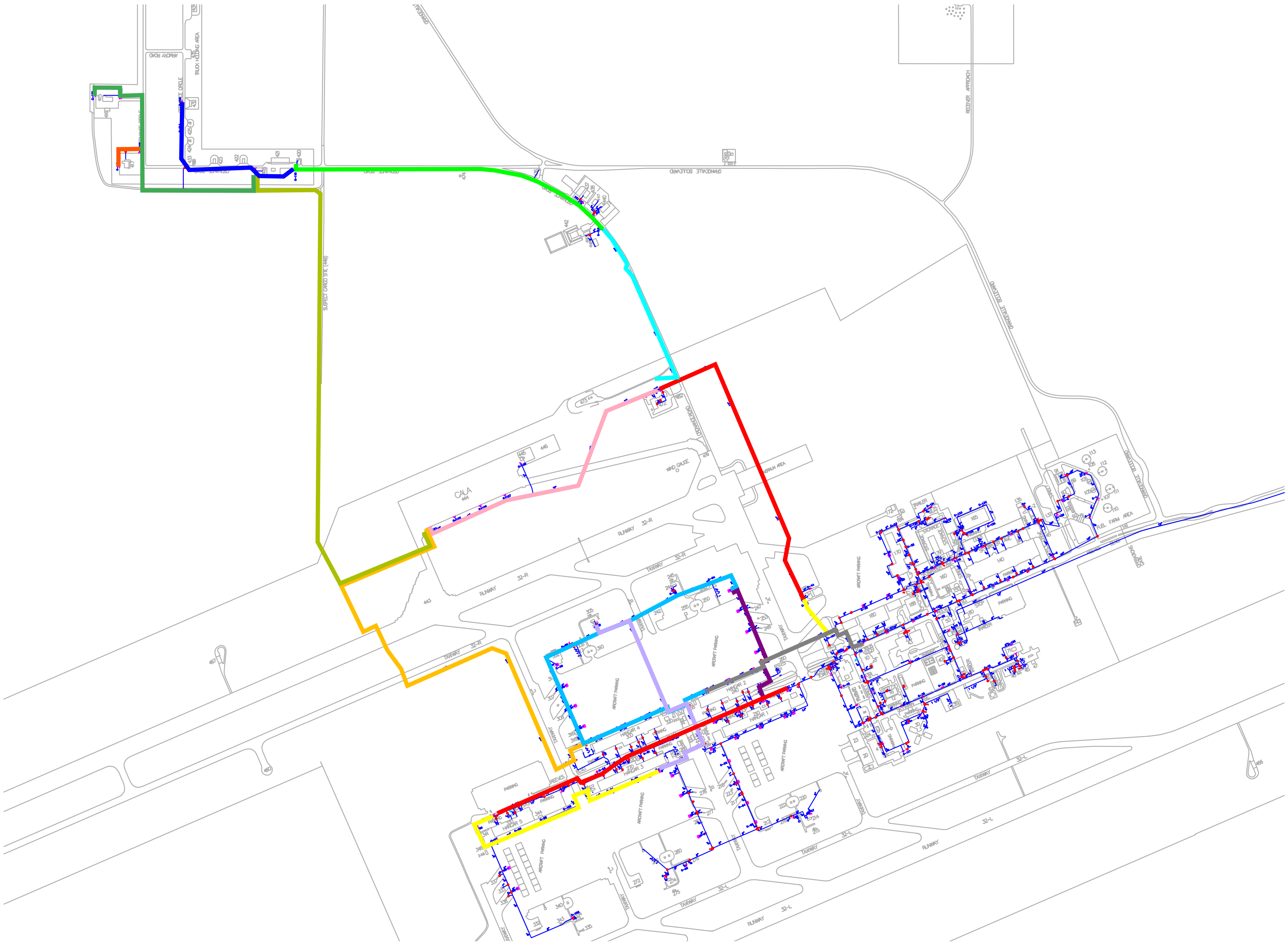
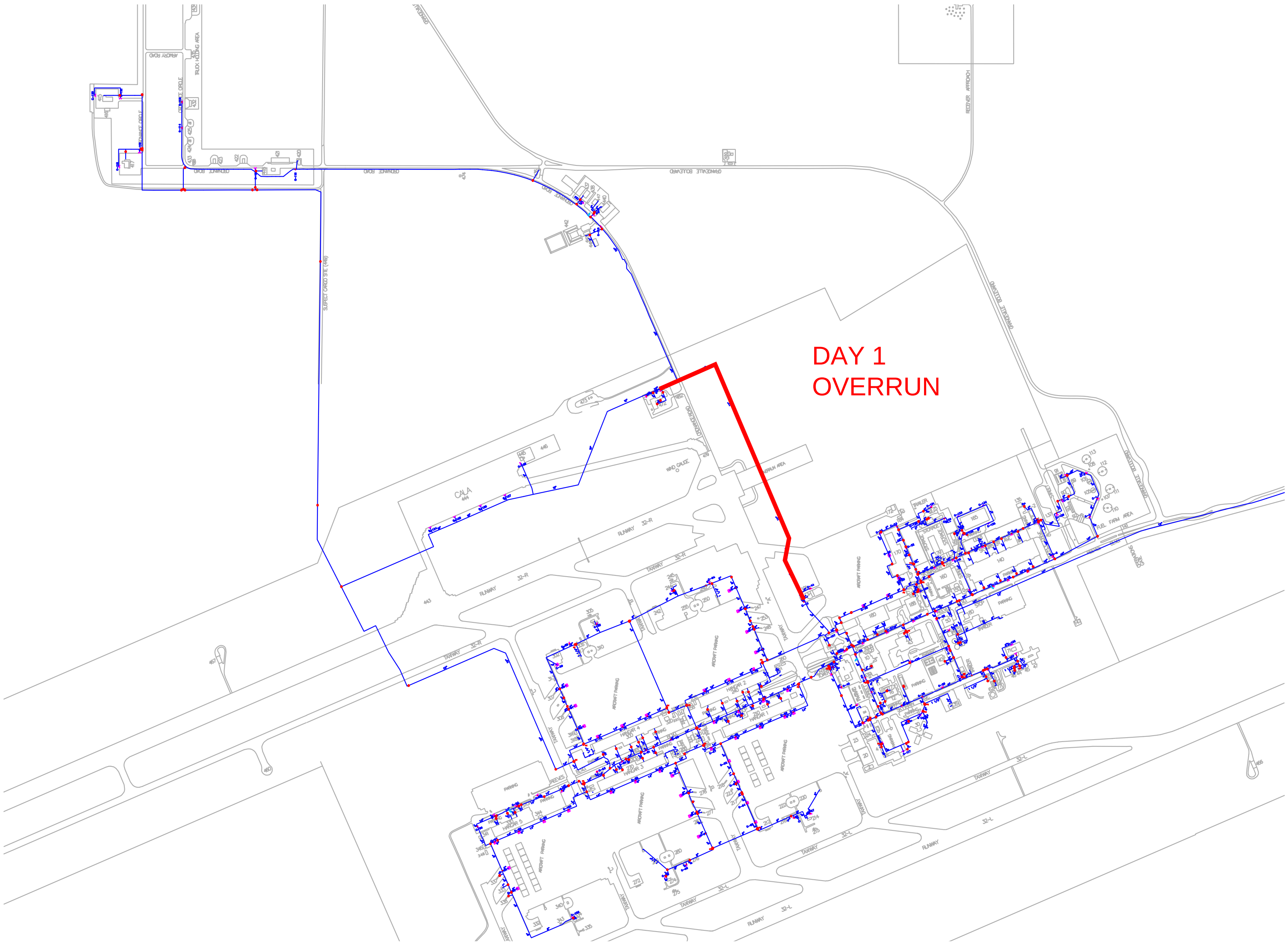
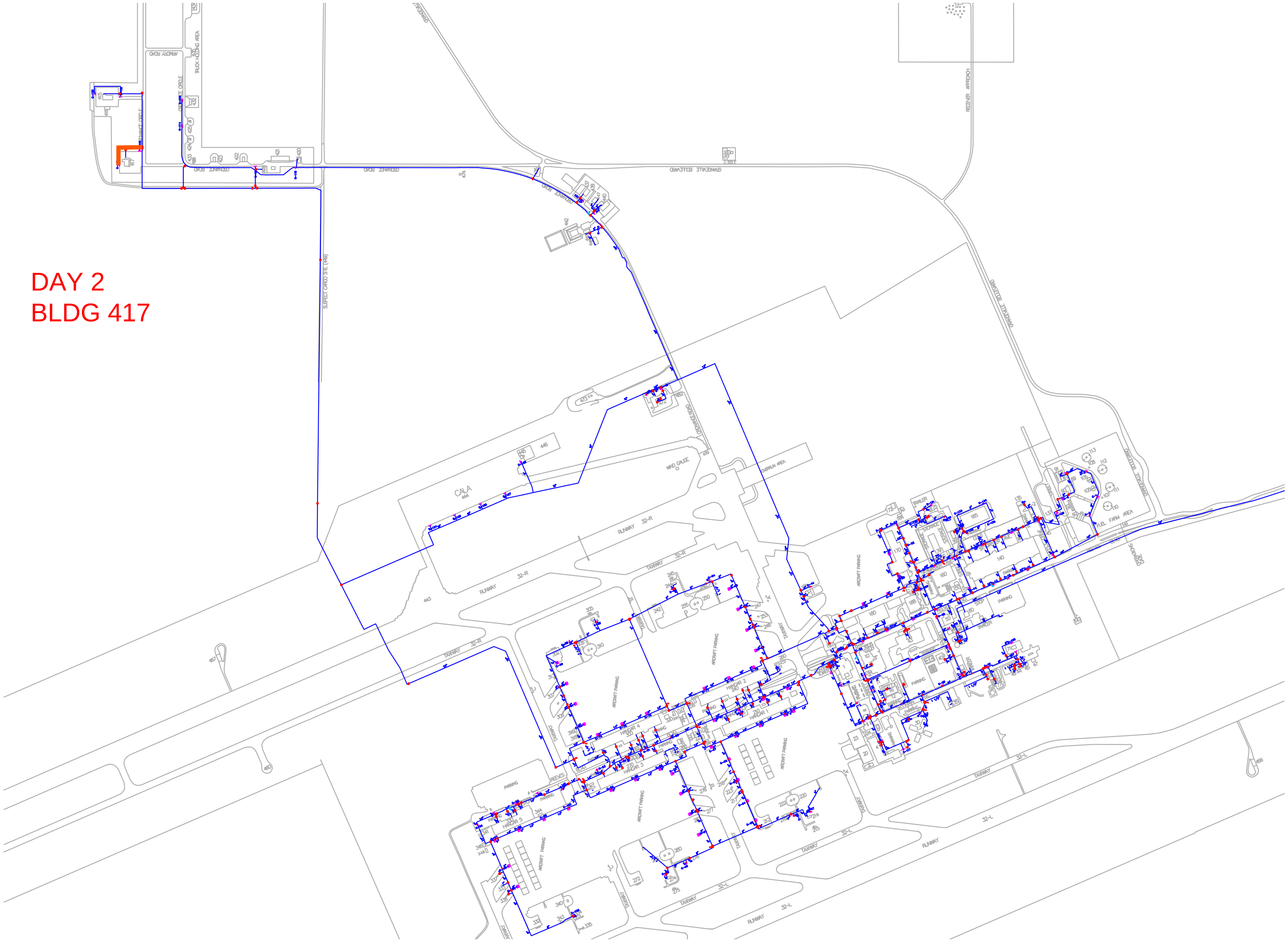
Date	Run #	Insertion Point	Discharge Point	Disposal Method	Length (FT)	Pipe Dia.(in)	Pipe Material	Ice Quantity (Gals)	Flush Water (Gals)	Salt Content (lbs)
Monday, April 18, 2016	OVERRUN	C43	C45	TANKER	3400	12	AC	2700	29959.5	1081
Wednesday, April 20, 2016	ORDINANCE RD 1	C45	C124	TANKER	3250	10,12	AC	2200	28638	881
Wednesday, April 20, 2016	BLDG 417	C119	C118	TANKER	500	10	AC	300	3060	120
Friday, April 22, 2016	RUNWAY 1 A	C74	C124	TANKER	6100	10,14	AC	2700	37326	1081
Monday, April 25, 2016	RUNWAY 1 B	C124	C74	TANKER	6100	10,14	AC	2700	37326	1081
Wednesday, April 27, 2016	GRANGEVILLE RD 1A	C124	C122	TANKER	6500	10	AC	2700	39774	1081
Friday, April 29, 2016	GRANGEVILLE RD 1B	C122	C124	TANKER	6500	10	AC	2700	39774	1081
Monday, May 02, 2016	TAXIWAY 1	C107	C44	TBD	820	8,16	AC	550	3211.5	220
Monday, May 02, 2016	GRANGEVILLE RD 3	C122	C120	TANKER	3050	6,10	AC	2100	18663	841
Wednesday, May 04, 2016	ORDINANCE RD 2	C116	C110	TANKER	3625	10	AC	2250	22182	901
Friday, May 06, 2016	ORDINANCE RD 4	C45	C110	TANKER	2200	10,12	AC	1400	19384.5	560
Friday, May 06, 2016	ORDINANCE RD 3	C116	C115	TANKER	2050	10	AC	1200	12544.5	480
Monday, May 09, 2016	AIRCRAFT PK 1	C77	C83	SEWER	5,100	8,14	AC	2700	19972.5	1081
Wednesday, May 11, 2016	AIRCRAFT PK 2	C48	C83	SEWER	1500	8,14	AC	850	5874	340
Wednesday, May 11, 2016	AIRCRAFT PK 3	C56	C86	SEWER	2,950	8,14,16	AC	1800	35380.5	721
Friday, May 13, 2016	HANGAR 2	C36	C77	TANKER	2,200	16	AC	2700	34462.5	1081

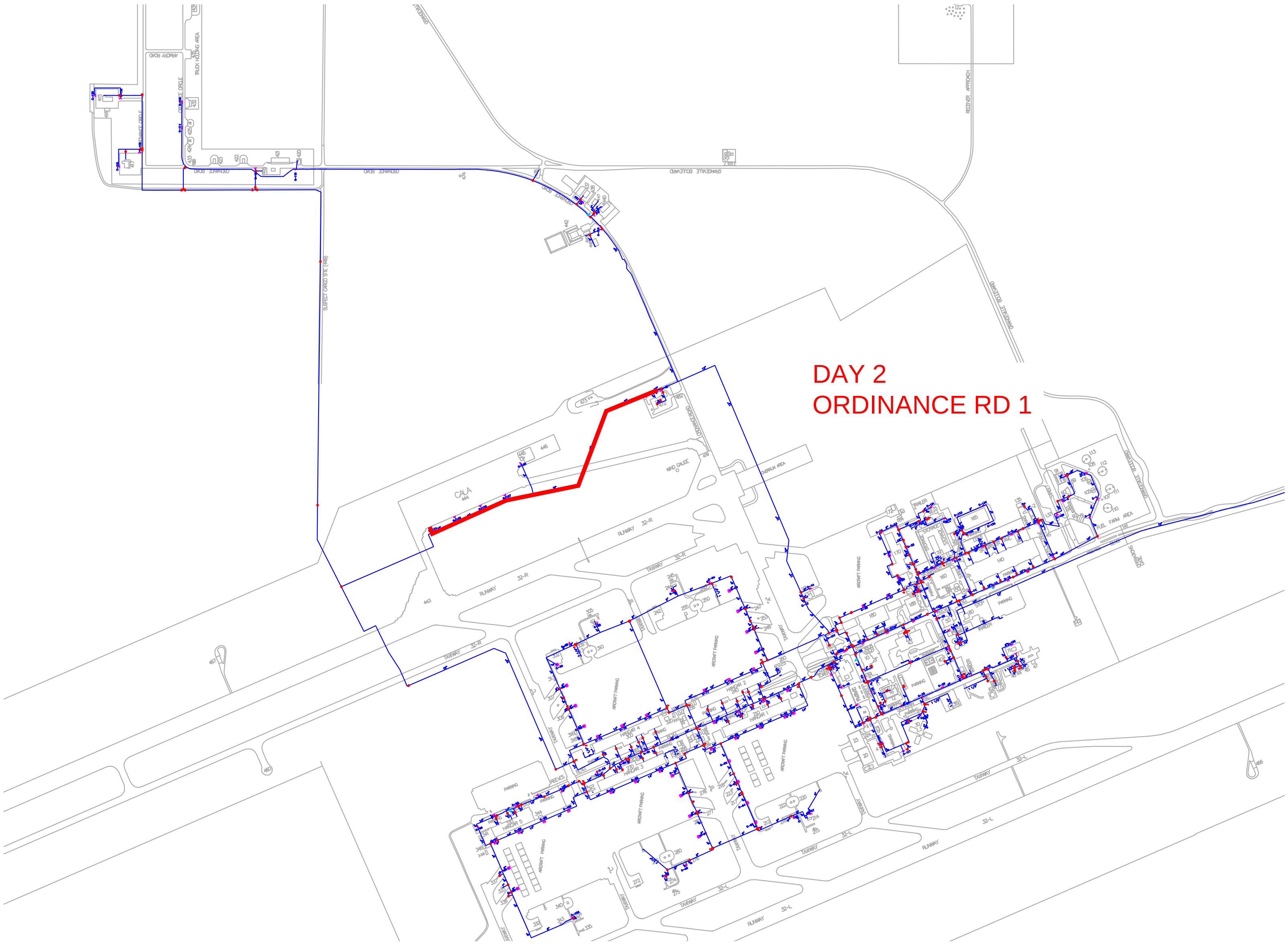

CALA
RUNWAY 32-R
TAXIWAY
AIRCRAFT PARKING
WIND GAUGE
FUEL FARM AREA


DAY 1
OVERRUN

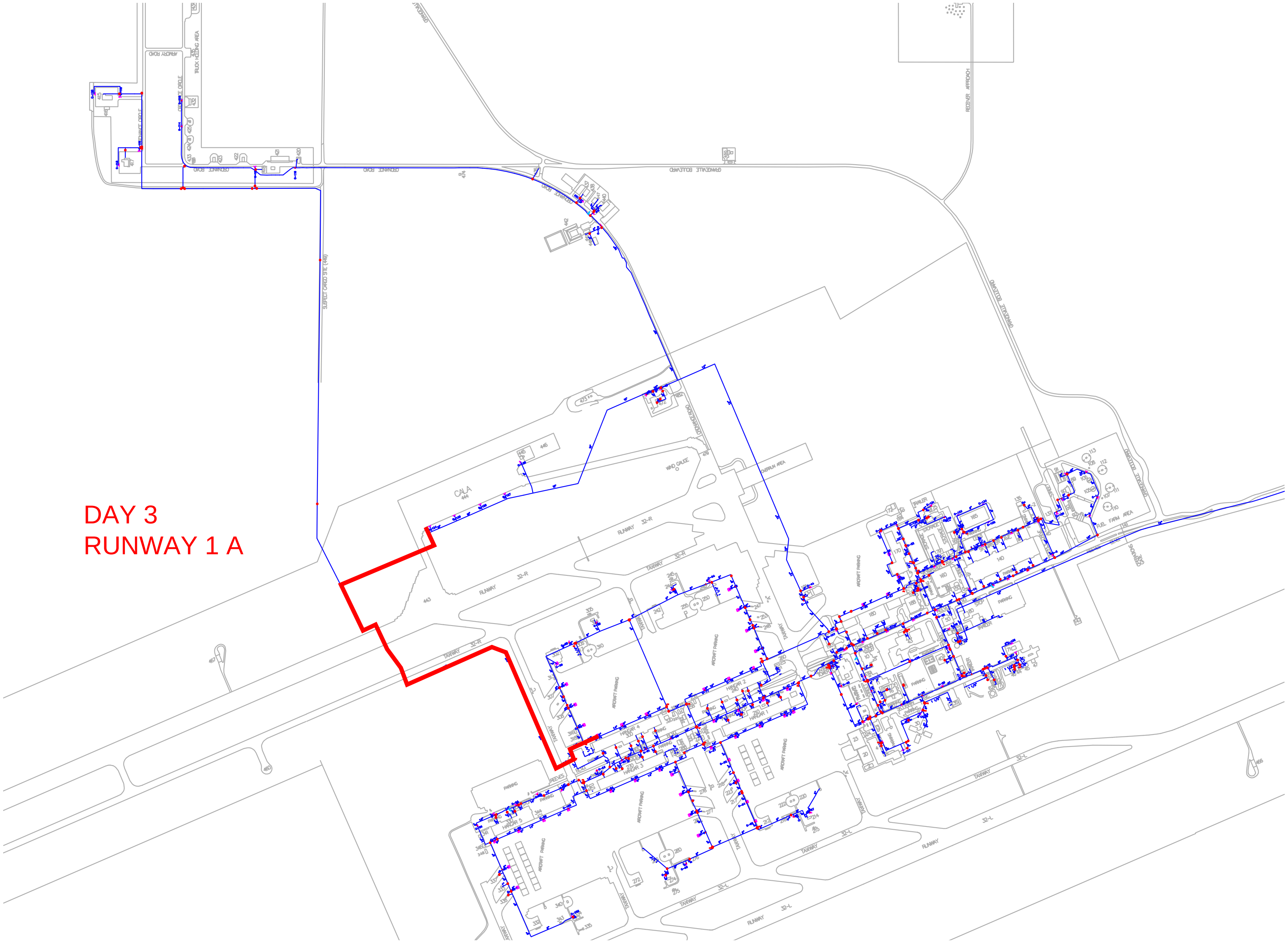
DAY 2
BLDG 417



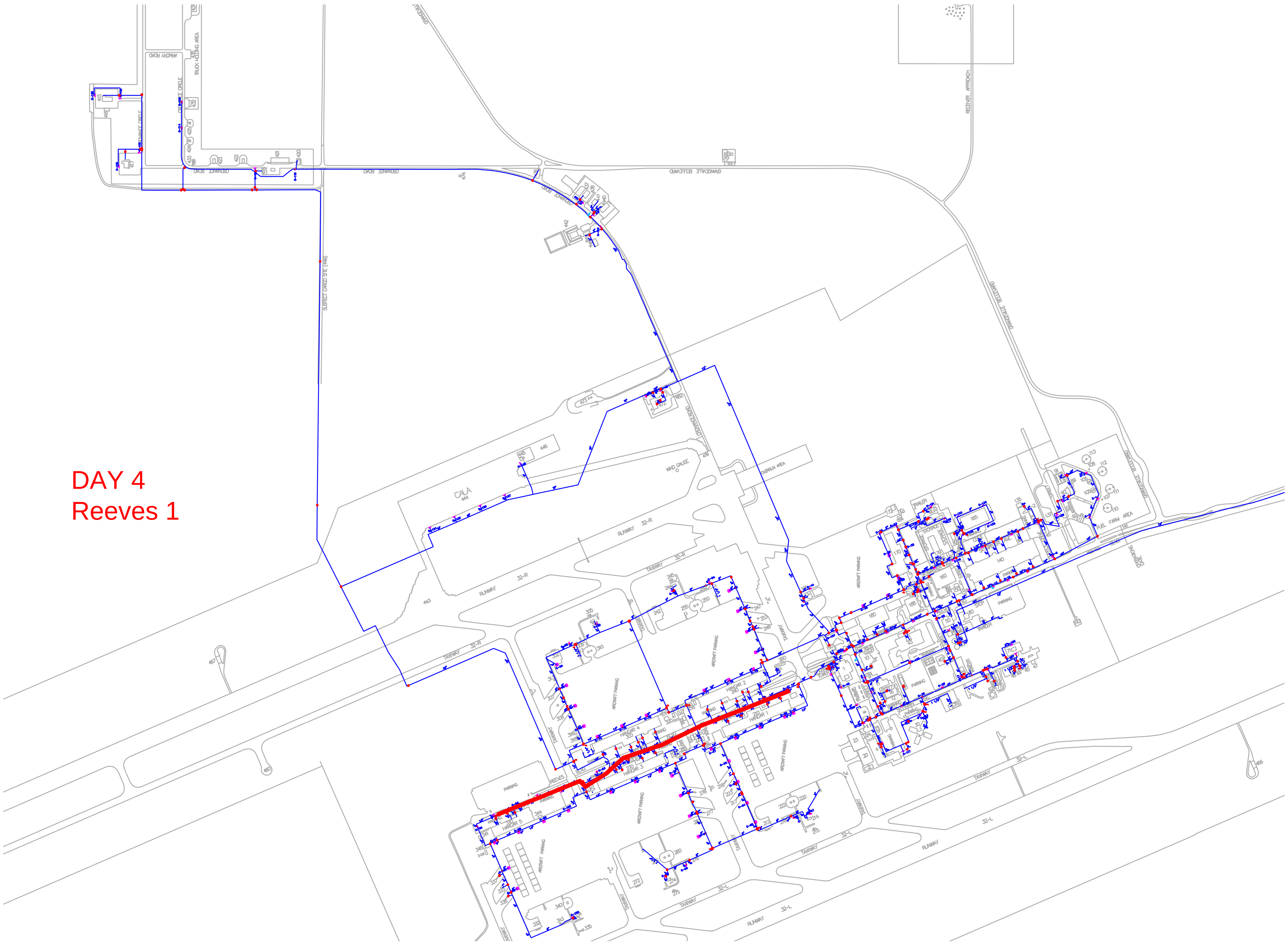
DAY 2
ORDINANCE RD 1



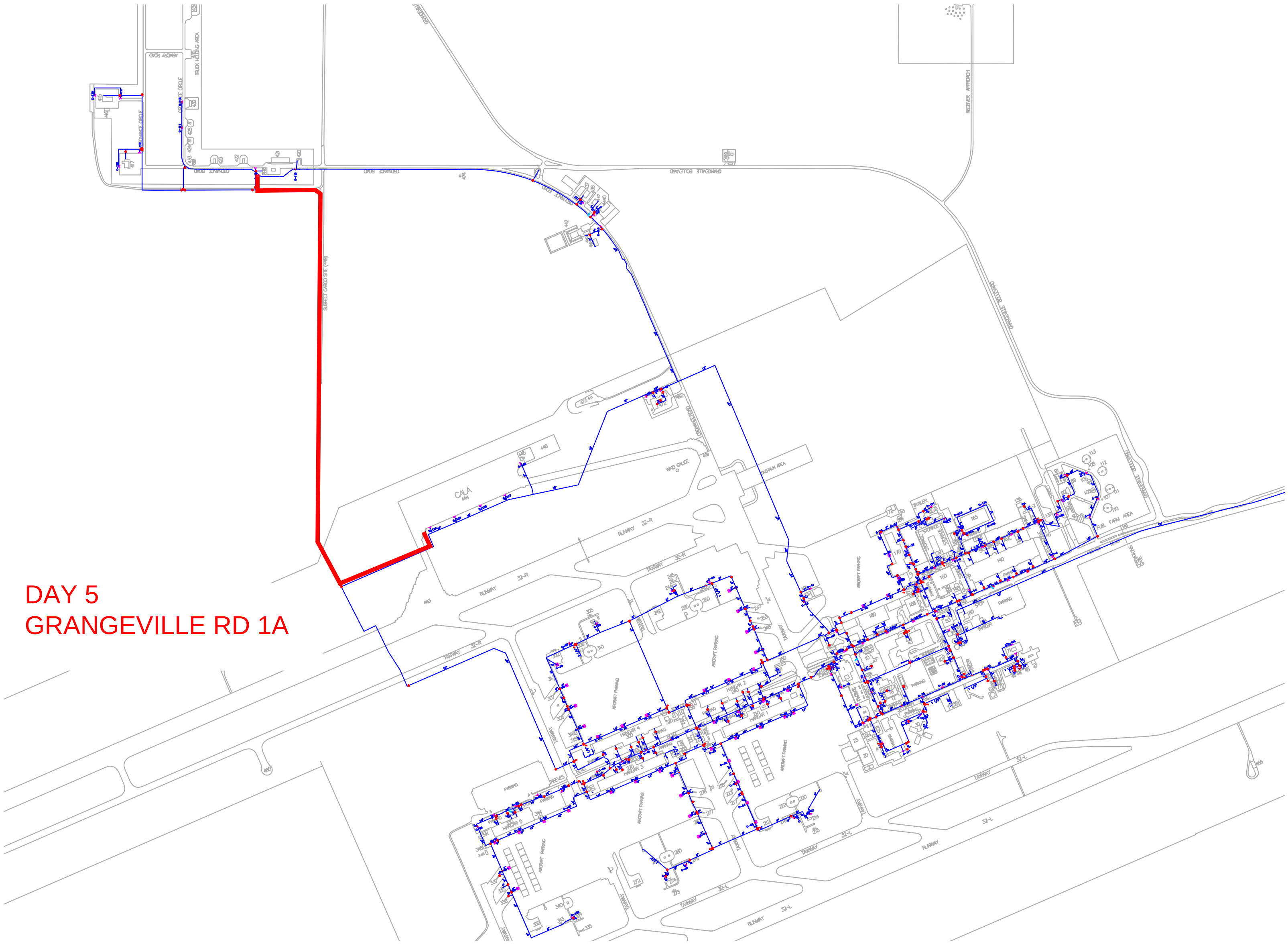
DAY 3
RUNWAY 1 A

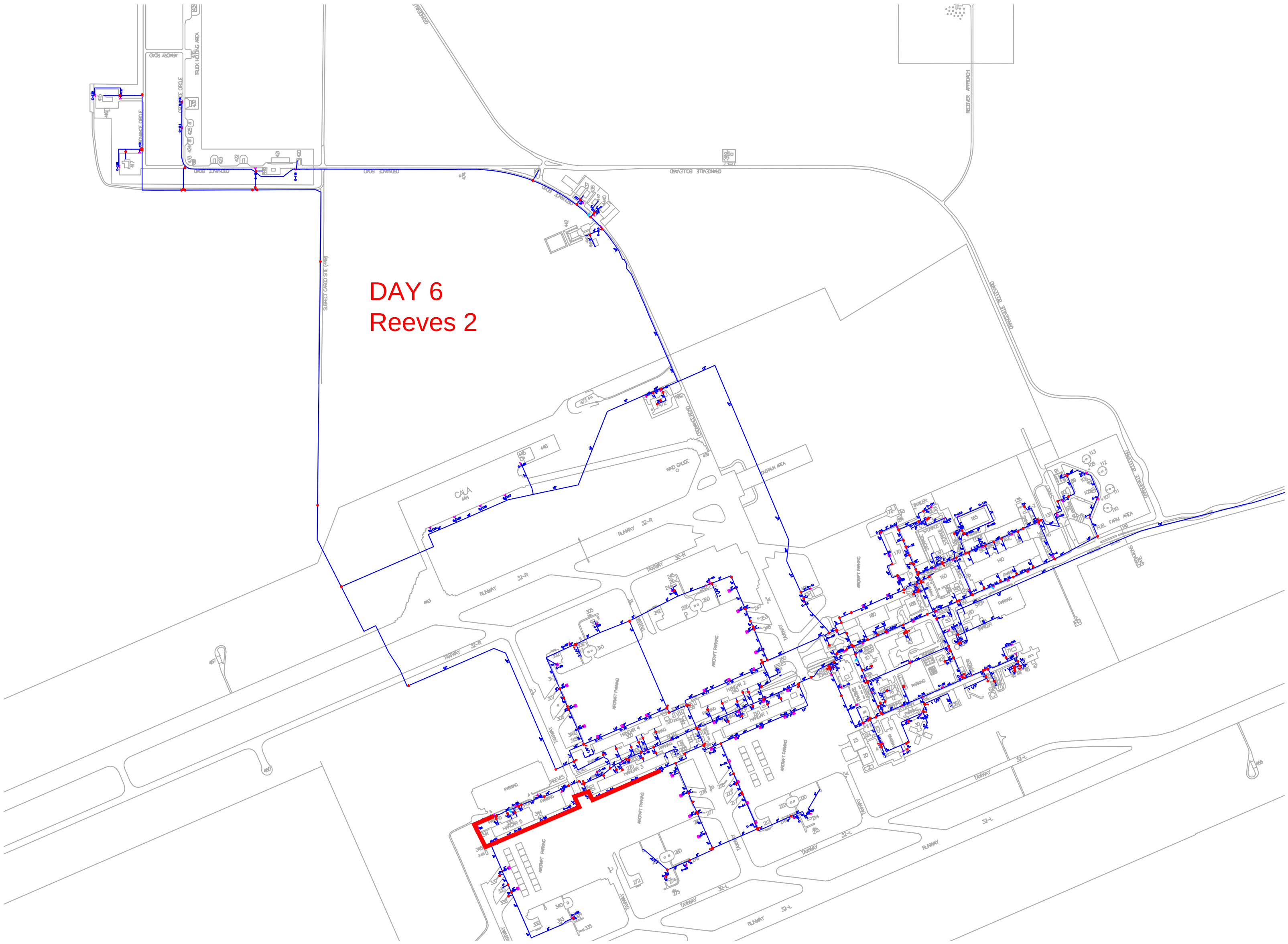


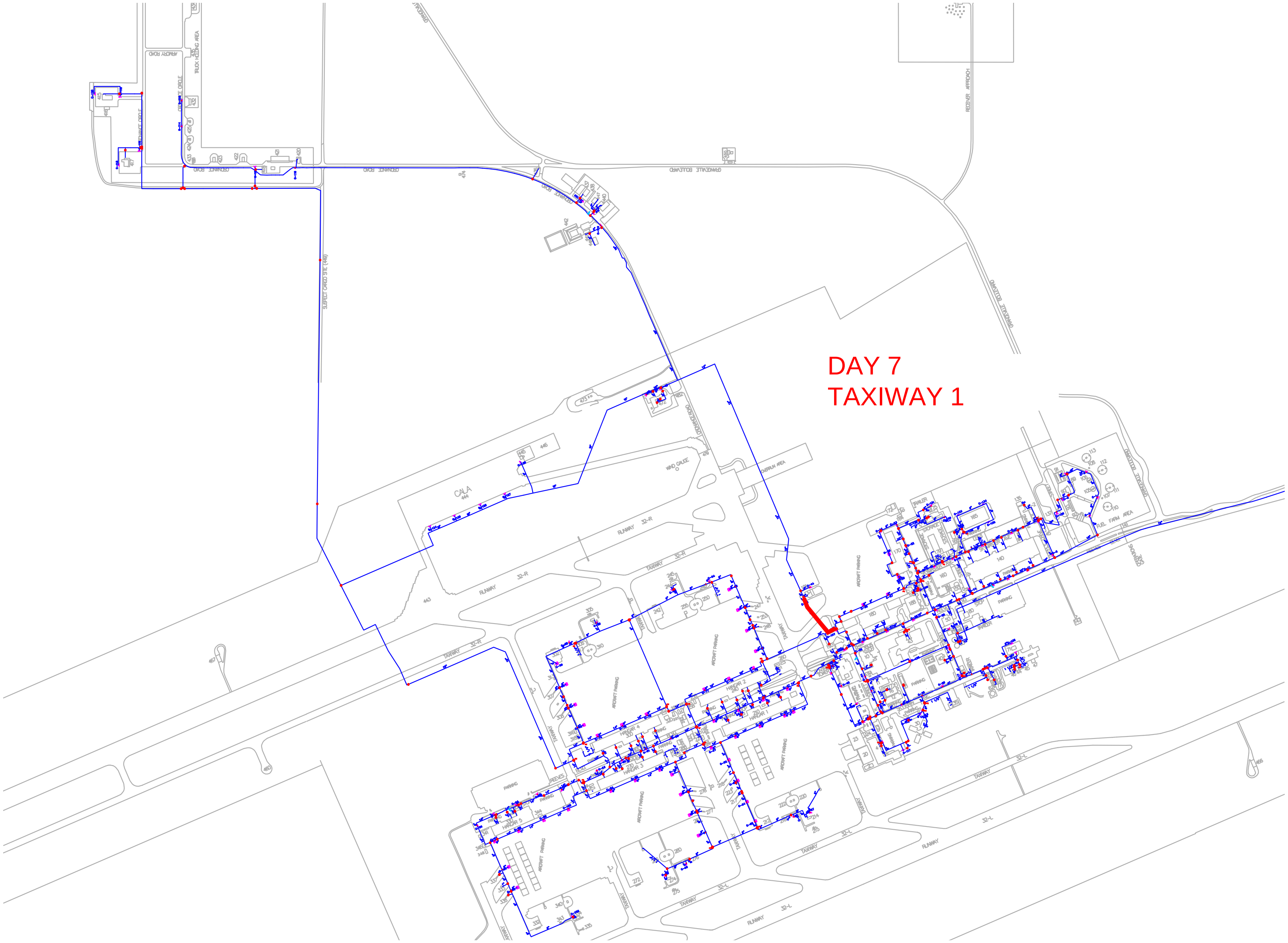
DAY 4
Reeves 1



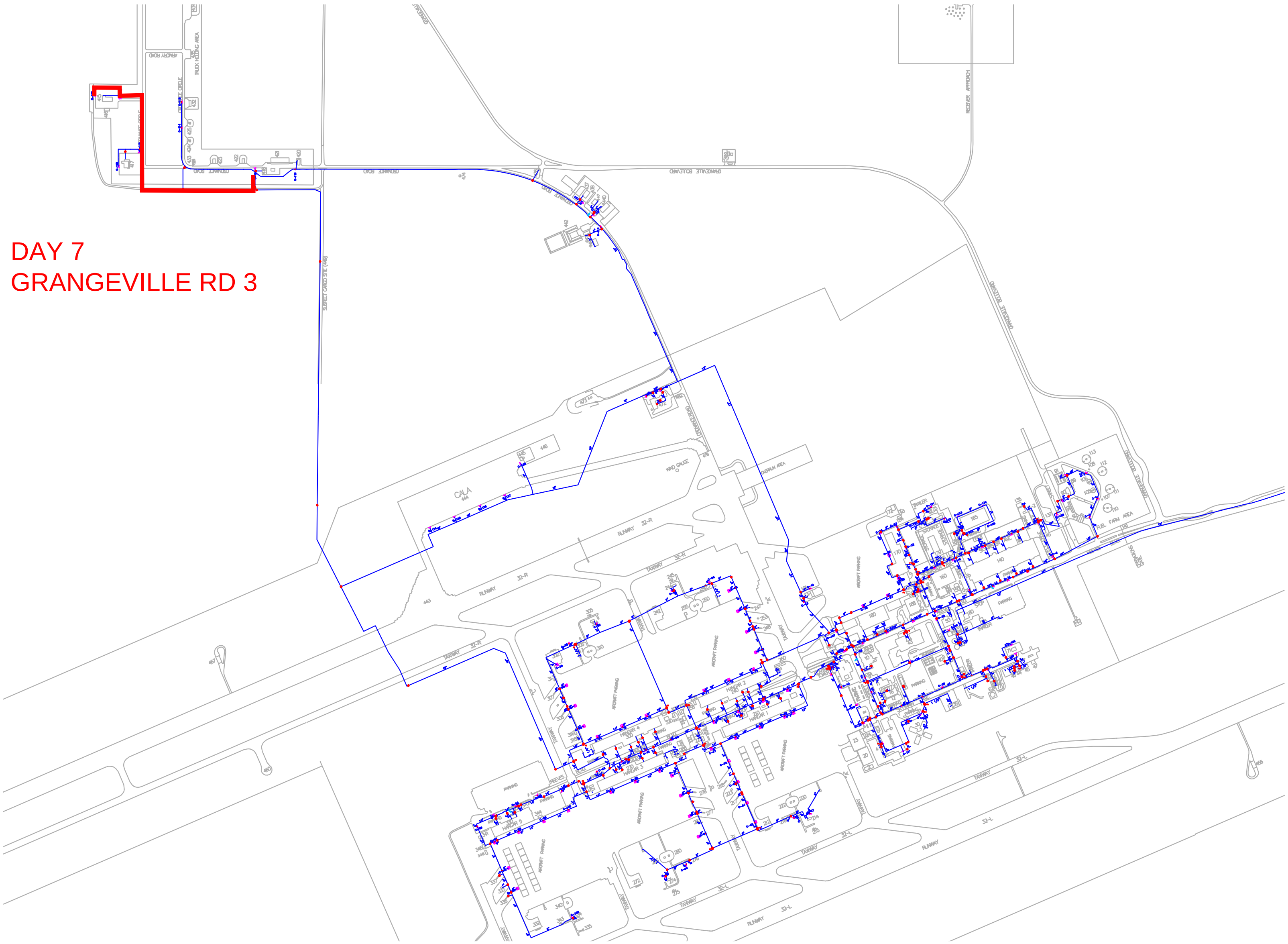
DAY 5
GRANGEVILLE RD 1A



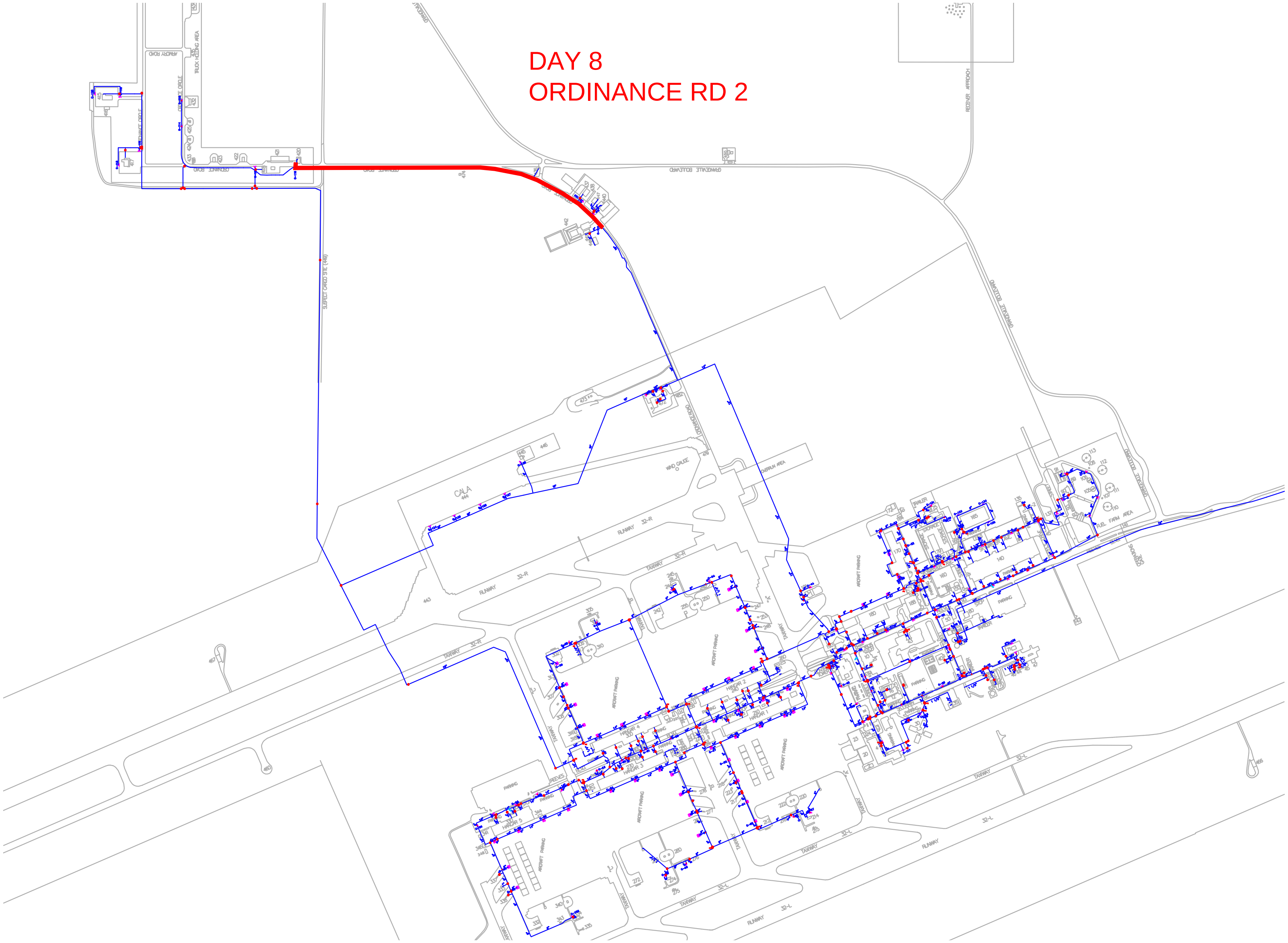

DAY 6
Reeves 2


DAY 7
TAXIWAY 1

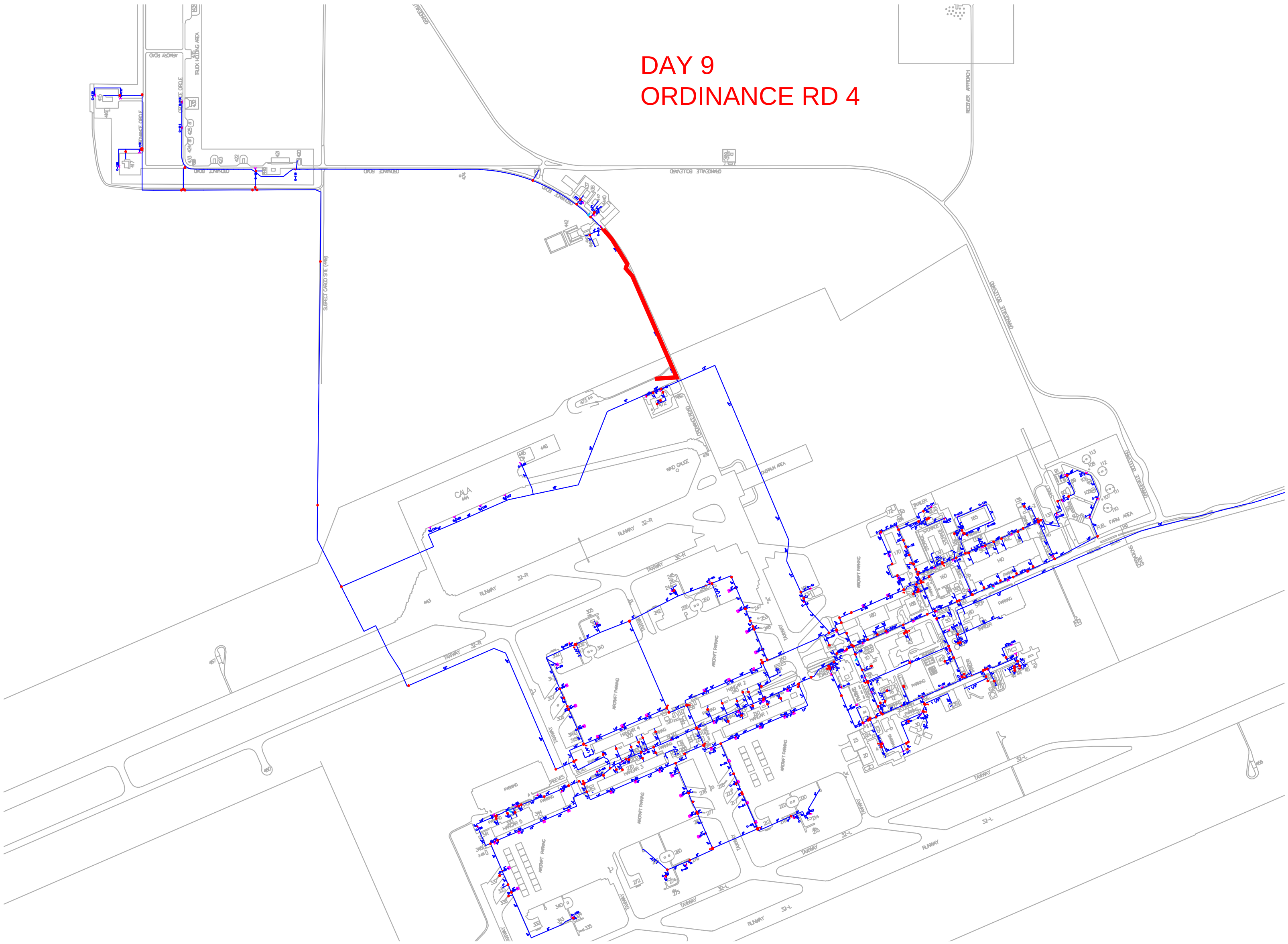
DAY 7
GRANGEVILLE RD 3



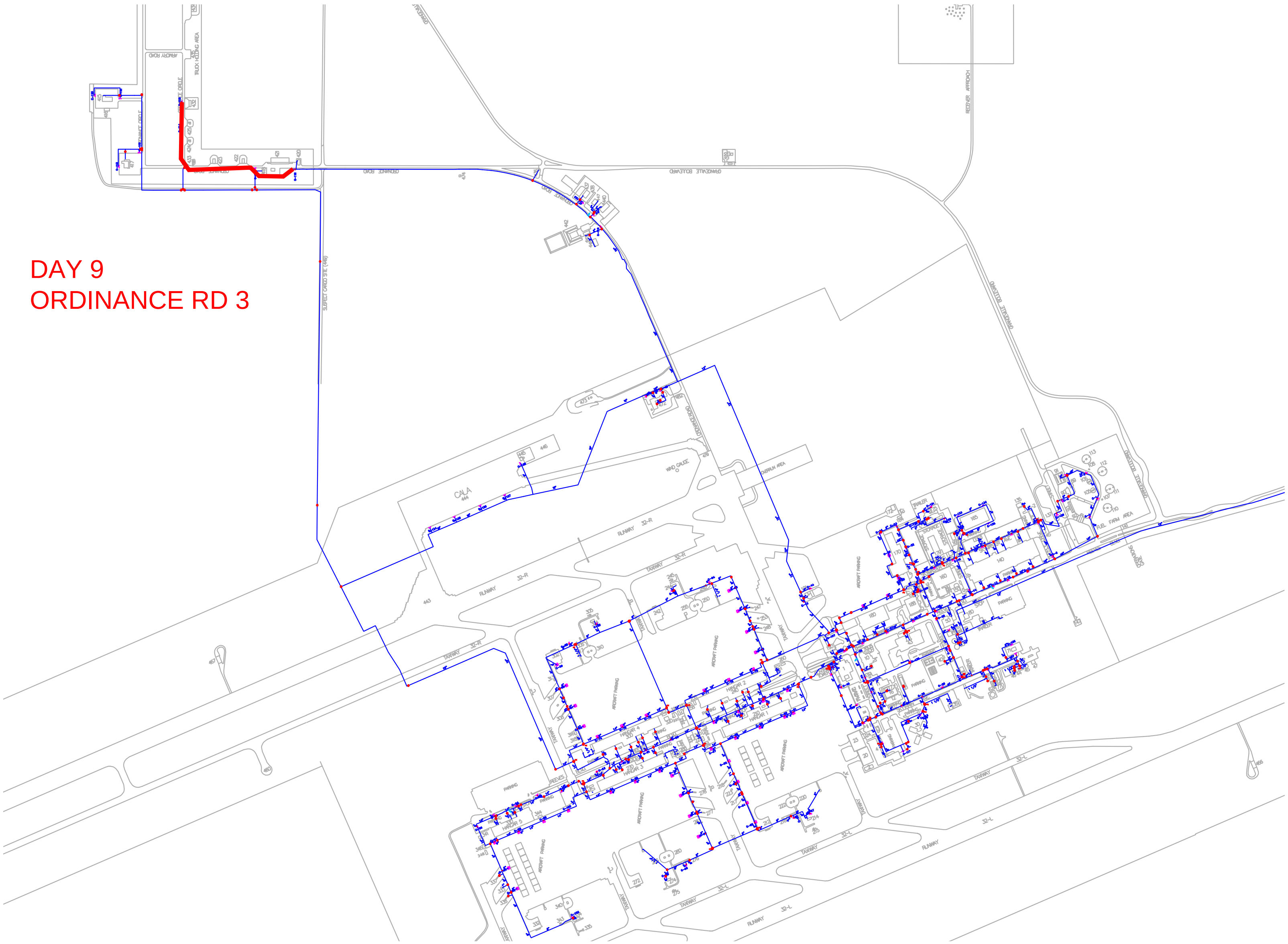
DAY 8
ORDINANCE RD 2

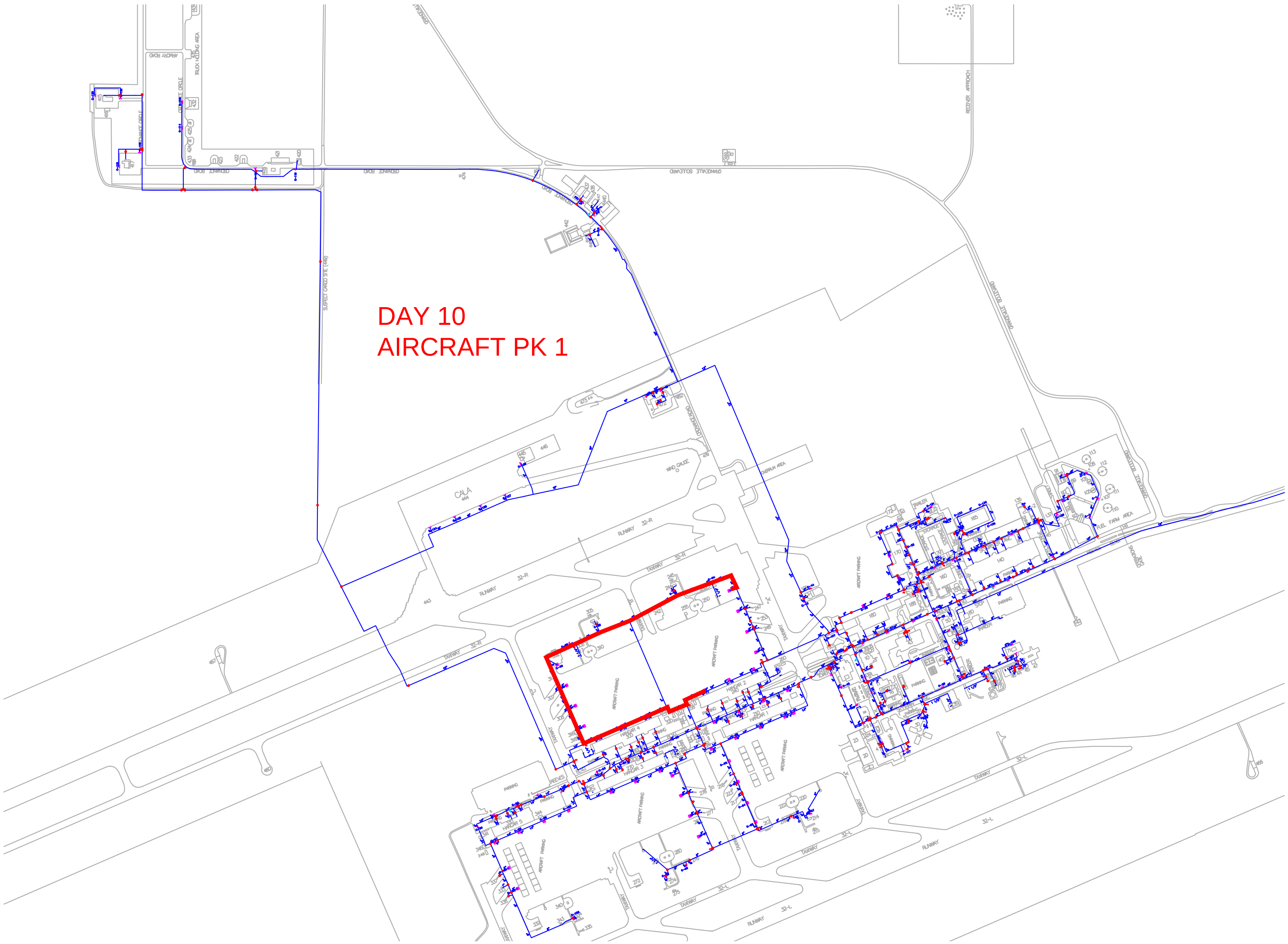


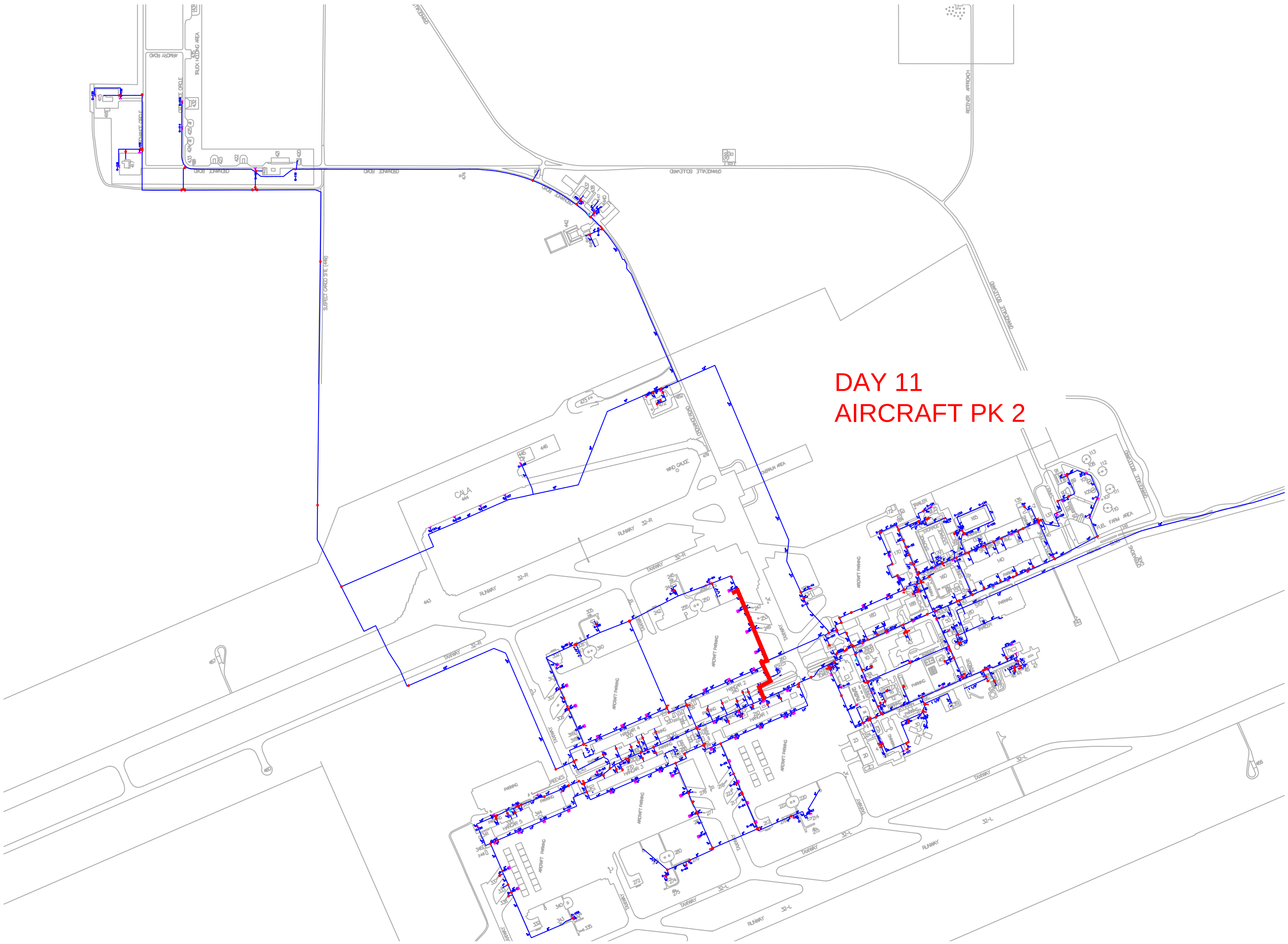
DAY 9
ORDINANCE RD 4



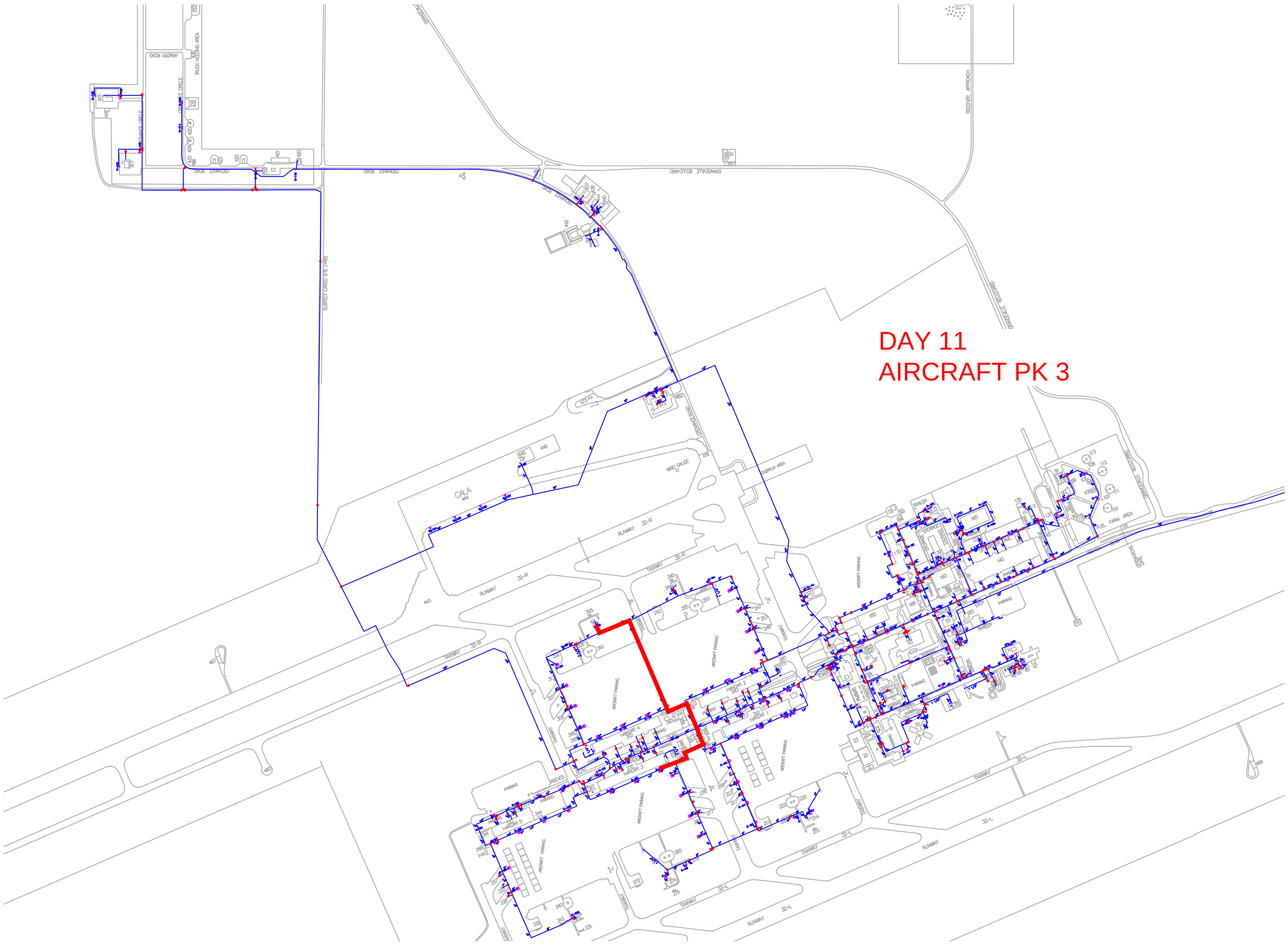
DAY 9
ORDINANCE RD 3

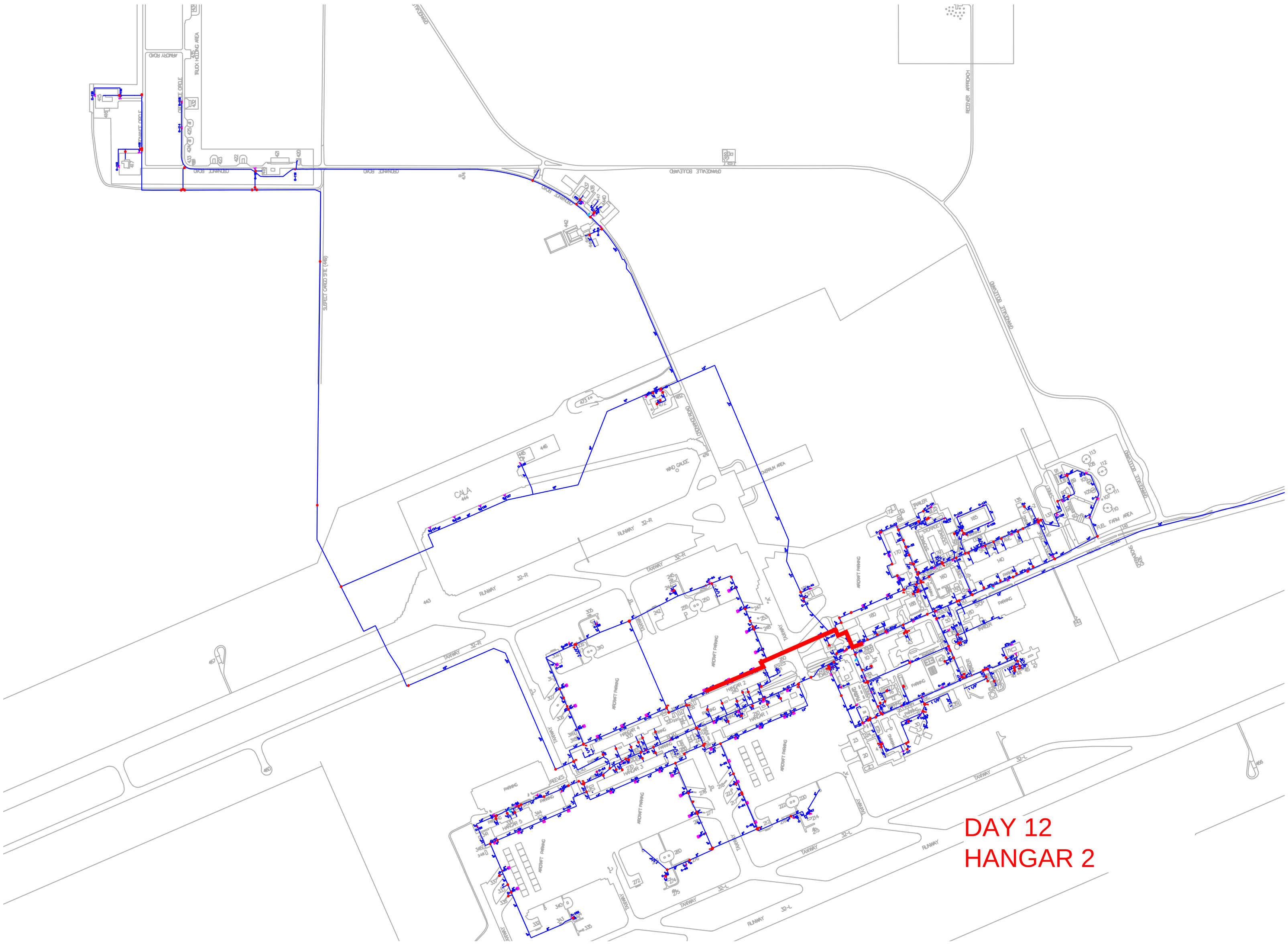



DAY 10
AIRCRAFT PK 1



DAY 11
AIRCRAFT PK 2


DAY 11
AIRCRAFT PK 3


DAY 12
HANGAR 2

Appendix D: Ice Pigging Field Reports

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ICE PIGGING

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	15-Jun-15
Location	SUSPECT CARGO
Insertion Point	C124
Discharge Point	C122
Pipe Length	6500 Lft
Pipe Diameter	10
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	2700 Gallons
Ice Fraction	90%
Total Water Used	Gallons

ONSITE PROCEDURE:

Pre-Clean Readings		Immediate Post-Clean Readings		Change
Turbidity (NTU)	1.4	Turbidity (NTU)	0.8	-0.6
Temperature (°F)	62	Temperature (°F)	58	-4
Pressure (PSI)	51	Pressure (PSI)	50	-1
Conductivity (mS/cm)	1.2	Conductivity (mS/cm)	1.2	0

Comments: .6 pt decrease in Turbidity from PRE to POST readings.

Maximum Flow Rate (gpm)	396	Lowest Temperature Reached (°F)	27.0	Ambient Air Temperature (°F)	73

#	Time (s)	Flow Rate (gal/m)	Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	372.00	0.03	89.28	0.196
2	120	372.00	0.06	178.56	0.393
3	180	372.00	0.09	267.84	0.589
4	240	372.00	0.15	446.40	0.982
5	300	372.00	0.07	208.32	0.458
6	360	372.00	0.09	267.84	0.589
7	420	372.00	0.08	238.08	0.524
8	480	372.00	0.08	238.08	0.524
9	540	372.00	0.08	238.08	0.524
10	600	372.00	0.08	238.08	0.524
11	660	372.00	0.09	267.84	0.589
12	720	372.00	0.07	208.32	0.458
13	780	372.00	0.13	386.88	0.851
14	840	372.00	0.06	178.56	0.393
15	900	372.00	0.07	208.32	0.458
16	960	372.00	0.06	178.56	0.393
17	1020	372.00	0.05	148.80	0.327
18	1080	372.00	0.06	178.56	0.393
19	1140	372.00	0.04	119.04	0.262
20	1200	372.00	0.04	119.04	0.262
21	1260	372.00	0.04	119.04	0.262
22	1320	372.00	0.04	119.04	0.262

RESULT:

Sediment Removed (lb)	10.21	Sediment Removed per mile (lb)	8.31

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	15-Jun-15
Location	REEVES
Insertion Point	C124
Discharge Point	C74
Pipe Length	6100 Lft
Pipe Diameter	10,14
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	2700 Gallons
Ice Fraction	90%
Total Water Used	Gallons

ONSITE PROCEDURE:

Pre-Clean Readings		**Immediate Post-Clean Readings**		**Change**
Turbidity (NTU)	2.3	Turbidity (NTU)	2.3	0
Temperature (°F)	67	Temperature (°F)	65	-2
Pressure (PSI)	50	Pressure (PSI)	70	20
Conductivity (mS/cm)	0.9	Conductivity (mS/cm)	1	0.1

Comments: 20 pt increase in pressure from PRE to POST readings.

Maximum Flow Rate (gpm)	396	Lowest Temperature Reached (°F)	27.0	Ambient Air Temperature (°F)	69

#	Time (s)	Flow Rate (gal/m)	Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	354.00	0.02	56.64	0.125
2	120	354.00	0.07	198.24	0.436
3	180	354.00	0.05	141.60	0.312
4	240	354.00	0.08	226.56	0.498
5	300	354.00	0.10	283.20	0.623
6	360	354.00	0.12	339.84	0.748
7	420	354.00	0.22	623.04	1.371
8	480	354.00	0.23	651.36	1.433
9	540	354.00	0.22	623.04	1.371
10	600	354.00	0.16	453.12	0.997
11	660	354.00	0.11	311.52	0.685
12	720	354.00	0.09	254.88	0.561
13	780	354.00	0.06	169.92	0.374
14	840	354.00	0.07	198.24	0.436
15	900	354.00	0.06	169.92	0.374
16	960	354.00	0.05	141.60	0.312
17	1020	354.00	0.03	84.96	0.187
18	1080	354.00	0.04	113.28	0.249
19	1140	354.00	0.02	56.64	0.125
20	1200	354.00	0.02	56.64	0.125

RESULT:

Sediment Removed (lb)	**11.34**	**Sediment Removed per mile (lb)**	**9.83**

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING

suez

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	20-Apr-16
Location	CALA
Insertion Point	C45
Discharge Point	C124
Pipe Length	3250 Lft
Pipe Diameter	10,12
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	2200 Gallons
Ice Fraction	90%
Total Water Used	Gallons

ONSITE PROCEDURE:

Pre-Clean Readings		**Immediate Post-Clean Readings**		**Change**
Turbidity (NTU)	2.5	Turbidity (NTU)	4.3	1.8
Temperature (°F)	61.9	Temperature (°F)	60.5	-1.4
Pressure (PSI)	49.8	Pressure (PSI)	46.3	-3.5
Conductivity (mS/cm)	1	Conductivity (mS/cm)	1.2	0.2

Comments: 29 pt drop in turbidity from PRE to POST readings.

Maximum Flow Rate (gpm)	396	Lowest Temperature Reached (°F)	27.0	Ambient Air Temperature (°F)	88

#	Time (s)	Flow Rate (gal/m)		Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	376.00		0.03	90.24	0.199
2	120	376.00		0.05	150.40	0.331
3	180	376.00		0.07	210.56	0.463
4	240	376.00		0.11	330.88	0.728
5	300	376.00		0.09	270.72	0.596
6	360	376.00		0.07	210.56	0.463
7	420	376.00		0.07	210.56	0.463
8	480	376.00		0.05	150.40	0.331
9	540	376.00		0.09	270.72	0.596
10	600	376.00		0.08	240.64	0.529
11	660	376.00		0.08	240.64	0.529
12	720	376.00		0.09	270.72	0.596
13	780	376.00		0.07	210.56	0.463
14	840	376.00		0.09	270.72	0.596
15	900	376.00		0.09	270.72	0.596
16	960	376.00		0.07	210.56	0.463
17	1020	376.00		0.09	270.72	0.596
18	1080	376.00		0.09	270.72	0.596
19	1140	376.00		0.03	90.24	0.199
20	1200	376.00		0.03	90.24	0.199
21	1260	376.00		0.05	150.40	0.331
22	1320	376.00		0.03	90.24	0.199
23	1380	376.00		0.02	60.16	0.132

RESULT:

Sediment Removed (lb)	**10.19**	**Sediment Removed per mile (lb)**	**16.58**

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING suez

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	20-Apr-16
Location	BLDG 417
Insertion Point	C119
Discharge Point	C118
Pipe Length	500 Lft
Pipe Diameter	10
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	300 Gallons
Ice Fraction	90%
Total Water Used	Gallons

ONSITE PROCEDURE:

Pre-Clean Readings		**Immediate Post-Clean Readings**		**Change**
Turbidity (NTU)	30.4	Turbidity (NTU)	0.9	-29.5
Temperature (°F)	61.8	Temperature (°F)	60.9	-0.9
Pressure (PSI)	40	Pressure (PSI)	40	0
Conductivity (mS/cm)	1	Conductivity (mS/cm)	1.1	0.1

Comments: 29 pt drop in turbidity from PRE to POST readings.

Maximum Flow Rate (gpm)	396	Lowest Temperature Reached (°F)	27.0	Ambient Air Temperature (°F)	88

#	Time (s)	Flow Rate (gal/m)		Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	396.00		0.04	126.72	0.279
2	120	396.00		0.05	158.40	0.348
3	180	396.00		0.26	823.68	1.812
4	240	396.00		0.12	380.16	0.836
5	300	396.00		0.08	253.44	0.558
6	360	396.00		0.08	253.44	0.558
7	420	396.00		0.08	253.44	0.558
8	480	396.00		0.06	190.08	0.418
9	540	396.00		0.06	190.08	0.418
10	600	396.00		0.07	221.76	0.488
11	660	396.00		0.05	158.40	0.348
12	720	396.00		0.07	221.76	0.488
13	780	396.00		0.05	158.40	0.348
14	840	396.00		0.04	126.72	0.279

RESULT:

Sediment Removed (lb)	**7.74**	**Sediment Removed per mile (lb)**	**81.83**

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	Lemoore NAS
Date	7-May-16
Location	Ordinance Rd 2
Insertion Point	C45
Discharge Point	C110
Pipe Length	2200 Lft
Pipe Diameter	10,12
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	1400 Gallons
Ice Fraction	90%
Total Water Used	9432 Gallons

ONSITE PROCEDURE:

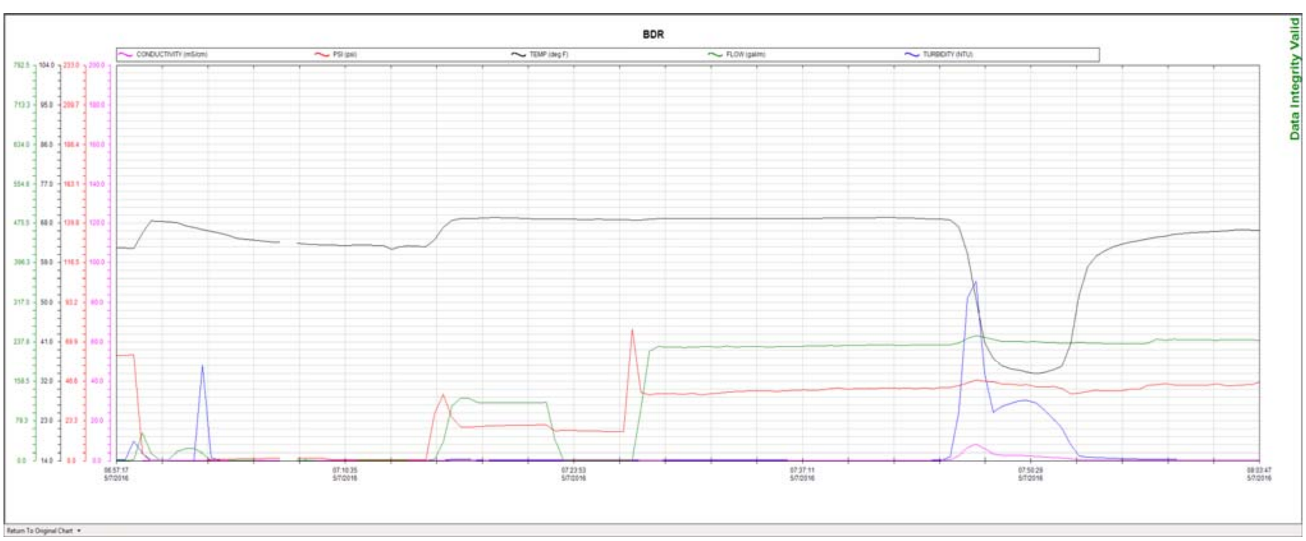
Pre-Clean Readings		**Immediate Post-Clean Readings**		**Change**
Turbidity (NTU)	1.7	Turbidity (NTU)	1.1	-0.6
Temperature (°F)	69	Temperature (°F)	68	-1
Pressure (PSI)	40	Pressure (PSI)	45	5
Conductivity (mS/cm)	0.3	Conductivity (mS/cm)	1.1	0.8

Timeline:

Arrive	3:45 AM
Pre Clean Readings	4:00 AM
Main Iso by Client	4:05 AM
Ice In	4:15 AM
Main Opened	4:27 AM
Conductivity Alarm	4:45 AM
Ice Out	4:52 AM
Post Clean Readings	5:04 AM
Main Returned to Svc	5:10 AM
Leave Site	5:12 AM

Comments:

Maximum Flow Rate (gpm)	247	Lowest Temperature Reached (°F)	33.9	Ambient Air Temperature (°F)	72



ICE PIGGING suez

JOB RECORD/REPORT/SUMMARY

SEDIMENT DATA:

#	Time (s)	Flow Rate (gal/m)	Temperature (°F)	Conductivity (mS/cm)	Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	233.60	67.9	1.5	0.03	56.06	0.123
2	120	247.70	55.9	7.2	0.13	257.61	0.567
3	180	244.80	39.0	4.5	0.21	411.26	0.905
4	240	238.65	35.2	2.8	0.21	400.93	0.882
5	300	238.15	34.3	2.6	0.18	342.94	0.754
6	360	237.35	33.9	2.1	0.11	208.87	0.460
7	420	235.60	35.0	1.5	0.07	131.94	0.290
8	480	235.75	46.2	0.8	0.08	150.88	0.332
9	540	236.10	55.0	0.5	0.07	132.22	0.291
10	600	234.80	61.1	0.4	0.06	112.70	0.248
11	660	234.35	62.9	0.4	0.06	112.49	0.247
12	720	234.50	63.9	0.4	0.04	75.04	0.165
13	780	238.95	64.6	0.3	0.03	57.35	0.126
14	840	241.20	65.0	0.3	0.03	57.89	0.127
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RESULT:

Sediment Removed (lb)	5.52	Sediment Removed per mile (lb)	13.27

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING

suez

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	11-May-16
Location	Aircraft Pk 2
Insertion Point	C48
Discharge Point	C83
Pipe Length	1500 Lft
Pipe Diameter	8,14
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	850 Gallons
Ice Fraction	90%
Total Water Used	14763 Gallons

ONSITE PROCEDURE:

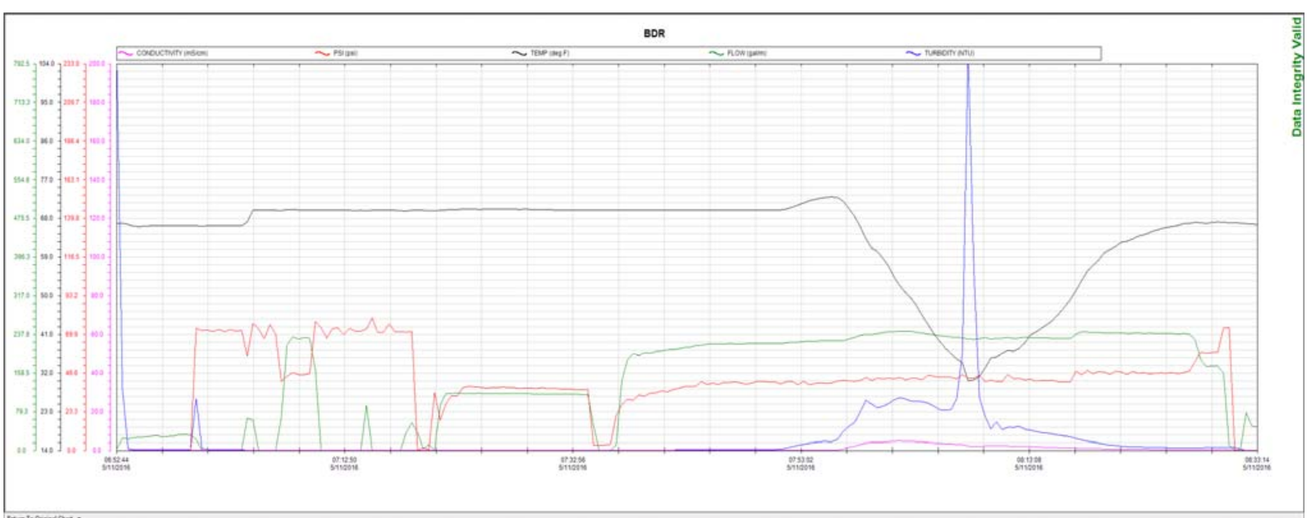
Pre-Clean Readings		**Immediate Post-Clean Readings**		**Change**
Turbidity (NTU)	0.9	Turbidity (NTU)	11.3	10.4
Temperature (°F)	74.5	Temperature (°F)	69.7	-4.8
Pressure (PSI)	47	Pressure (PSI)	51	4
Conductivity (mS/cm)	0.2	Conductivity (mS/cm)	0.7	0.5

Timeline:

- Arrive 3:55 AM
- Pre Clean Readings 4:05 AM
- Main Iso by Client 4:19 AM
- Ice In 4:21 AM
- Main Opened 4:36 AM
- Conductivity Alarm 4:57 AM
- Ice Out 5:09 AM
- Post Clean Readings 5:31 AM
- Main Returned to Svc 5:40 AM
- Leave Site 5:45 AM

Comments:

Maximum Flow Rate (gpm)	244	Lowest Temperature Reached (°F)	30.3	Ambient Air Temperature (°F)	91



ICE PIGGING suez

JOB RECORD/REPORT/SUMMARY

SEDIMENT DATA:

#	Time (s)	Flow Rate (gal/m)	Temperature (°F)	Conductivity (mS/cm)	Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	230.05	69.4	1.9	0.06	110.42	0.243
2	120	236.80	64.7	3.4	0.08	151.55	0.333
3	180	238.60	60.7	4.1	0.10	190.88	0.420
4	240	242.35	57.8	4.4	0.11	213.27	0.469
5	300	244.20	53.3	4.9	0.14	273.50	0.602
6	360	244.35	50.1	4.8	0.15	293.22	0.645
7	420	241.40	46.4	4.4	0.21	405.55	0.892
8	480	237.60	42.2	3.9	0.43	817.34	1.798
9	540	236.00	40.3	3.6	0.17	320.96	0.706
10	600	233.20	37.2	3.3	0.06	111.94	0.246
11	660	231.50	34.9	3.1	0.07	129.64	0.285
12	720	228.00	30.3	2.2	0.06	109.44	0.241
13	780	230.35	32.2	2.3	0.07	129.00	0.284
14	840	229.05	35.7	2.3	0.04	73.30	0.161
15	900	230.80	37.0	2.3	0.03	55.39	0.122
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RESULT:

Sediment Removed (lb)	7.45	Sediment Removed per mile (lb)	26.26

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	7-May-16
Location	Ordinance Rd Circle
Insertion Point	C116
Discharge Point	C115
Pipe Length	2050 Lft
Pipe Diameter	10
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	1200 Gallons
Ice Fraction	90%
Total Water Used	7810 Gallons

ONSITE PROCEDURE:

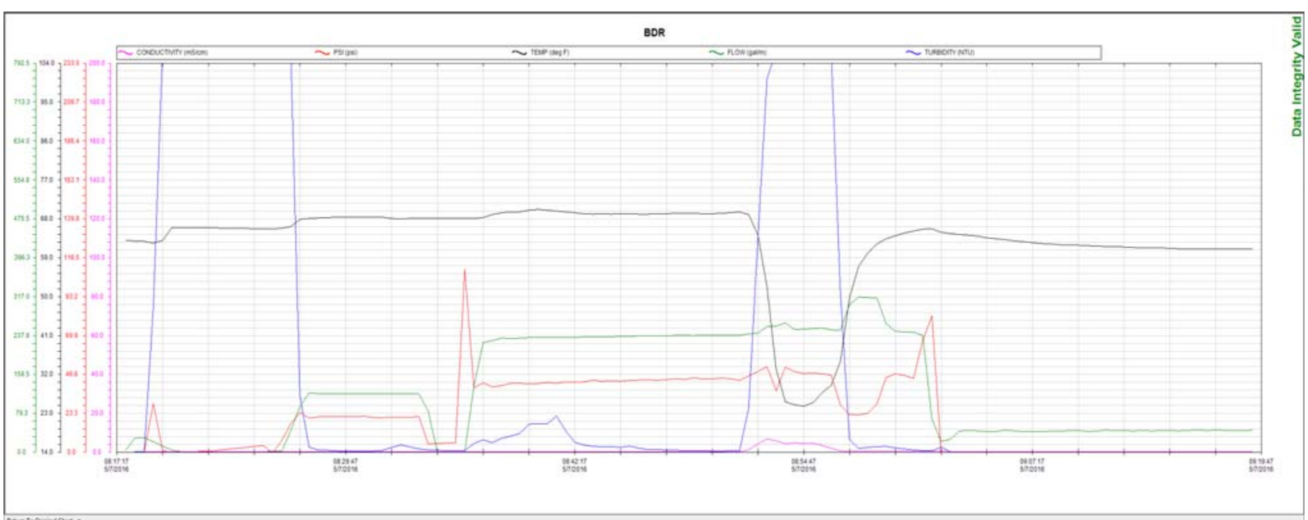
Pre-Clean Readings		**Immediate Post-Clean Readings**		**Change**
Turbidity (NTU)	10.4	Turbidity (NTU)	3.1	-7.3
Temperature (°F)	68	Temperature (°F)	65	-3
Pressure (PSI)	50	Pressure (PSI)	43	-7
Conductivity (mS/cm)	0.2	Conductivity (mS/cm)	0.3	0.1

Timeline:

- Arrive 5:15 AM
- Pre Clean Readings 5:18 AM
- Main Iso by Client 5:20 AM
- Ice In 5:26 AM
- Main Opened 5:37 AM
- Conductivity Alarm 5:52 AM
- Ice Out 5:58 AM
- Post Clean Readings 6:18 AM
- Main Returned to Svc 6:25 AM
- Leave Site 6:30 AM

Comments: 7 point drop in turbidity from PRE to POST readings.

Maximum Flow Rate (gpm)	315	Lowest Temperature Reached (°F)	25.0	Ambient Air Temperature (°F)	72



ICE PIGGING

JOB RECORD/REPORT/SUMMARY

SEDIMENT DATA:

#	Time (s)	Flow Rate (gal/m)	Temperature (°F)	Conductivity (mS/cm)	Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	242.05	66.7	2.6	0.03	58.09	0.128
2	120	246.80	42.7	6.3	0.29	572.58	1.260
3	180	249.65	25.3	4.5	0.36	718.99	1.582
4	240	260.50	25.0	4.5	0.36	750.24	1.651
5	300	250.35	28.6	2.7	0.55	1101.54	2.423
6	360	252.65	42.3	0.5	0.64	1293.57	2.846
7	420	249.45	58.6	0.3	0.16	319.30	0.702
8	480	308.60	62.8	0.4	0.13	320.94	0.706
9	540	315.95	63.8	0.4	0.10	252.76	0.556
10	600	288.30	65.0	0.3	0.09	207.58	0.457
11	660	246.10	65.7	0.3	0.08	157.50	0.347
12	720	241.55	64.8	0.4	0.06	115.94	0.255
13	780	44.40	64.3	0.2	0.05	17.76	0.039
14	840	34.25	63.8	0.1	0.04	10.96	0.024
15	900	43.45	63.3	0.1	0.03	10.43	0.023
16	960	41.60	62.8	0.1	0.04	13.31	0.029
17	1020	43.75	62.4	0.1	0.03	10.50	0.023
18	1080	41.35	62.1	0.1	0.02	6.62	0.015
19	1140	41.80	61.9	0.1	0.03	10.03	0.022
20	1200	42.90	61.8	0.1	0.03	10.30	0.023
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RESULT:

Sediment Removed (lb)	13.11	Sediment Removed per mile (lb)	33.82

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	13-May-16
Location	Hangar 2
Insertion Point	C36
Discharge Point	C77
Pipe Length	2200 Lft
Pipe Diameter	16
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	2700 Gallons
Ice Fraction	90%
Total Water Used	16797 Gallons

ONSITE PROCEDURE:

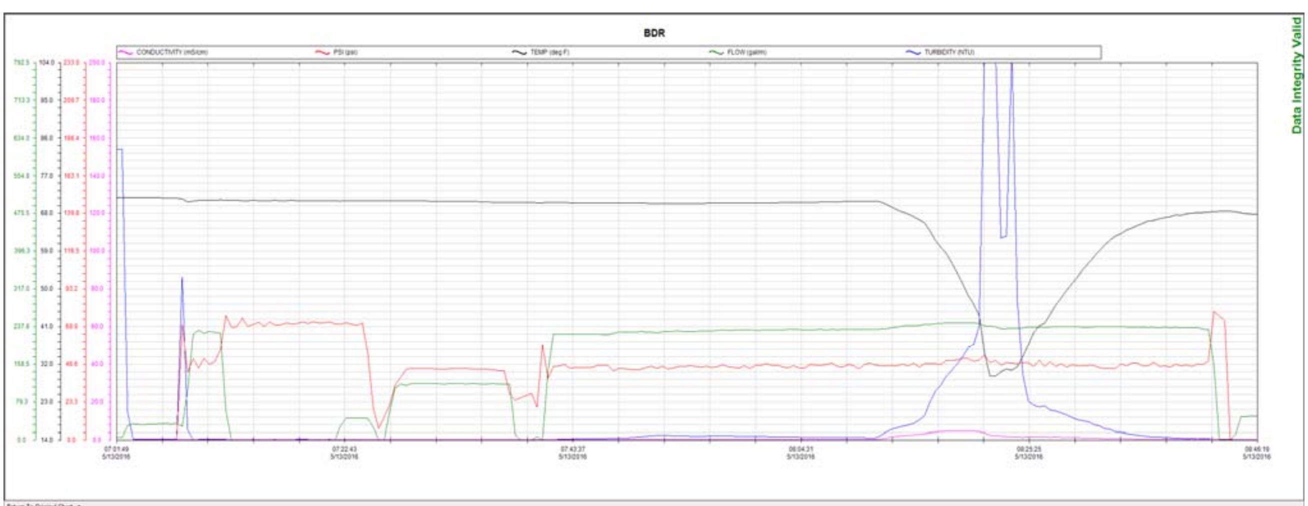
Pre-Clean Readings		Immediate Post-Clean Readings		Change
Turbidity (NTU)	0.8	Turbidity (NTU)	1.2	0.4
Temperature (°F)	71.2	Temperature (°F)	66.5	-4.7
Pressure (PSI)	48.1	Pressure (PSI)	44.5	-3.6
Conductivity (mS/cm)	0.2	Conductivity (mS/cm)	0.4	0.2

Timeline:

- Arrive 3:45 AM
- Pre Clean Readings 4:05 AM
- Main Iso by Client 4:21 AM
- Ice In 4:26 AM
- Main Opened 4:40 AM
- Conductivity Alarm 5:13 AM
- Ice Out 5:24 AM
- Post Clean Readings 5:44 AM
- Main Returned to Svc 5:50 AM
- Leave Site 6:00 AM

Comments: Schedule was change to only 1 run for the day, due to a broken gate valve.

Maximum Flow Rate (gpm)	245	Lowest Temperature Reached (°F)	29.1	Ambient Air Temperature (°F)	93



JOB RECORD/REPORT/SUMMARY

SEDIMENT DATA:

#	Time (s)	Flow Rate (gal/m)	Temperature (°F)	Conductivity (mS/cm)	Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	234.20	69.8	1.3	0.03	56.21	0.124
2	120	237.80	68.6	2.1	0.10	190.24	0.419
3	180	239.55	67.5	2.5	0.14	268.30	0.590
4	240	241.20	66.1	3.1	0.16	308.74	0.679
5	300	242.95	62.7	3.9	0.18	349.85	0.770
6	360	244.90	59.2	4.5	0.21	411.43	0.905
7	420	245.40	55.0	4.8	0.39	765.65	1.684
8	480	245.55	49.8	4.8	0.36	707.18	1.556
9	540	245.50	47.4	4.8	0.41	805.24	1.772
10	600	241.70	39.2	4.0	0.33	638.09	1.404
11	660	238.10	29.1	2.3	0.23	438.10	0.964
12	720	233.30	30.5	1.9	0.26	485.26	1.068
13	780	234.15	31.0	1.5	0.26	487.03	1.071
14	840	235.80	35.3	1.5	0.21	396.14	0.872
15	900	236.55	40.4	1.6	0.20	378.48	0.833
16	960	236.40	42.9	1.5	0.19	359.33	0.791
17	1020	237.40	47.0	1.5	0.17	322.86	0.710
18	1080	237.15	50.4	1.3	0.16	303.55	0.668
19	1140	236.95	53.7	1.2	0.05	94.78	0.209
20	1200	236.75	56.9	1.0	0.04	75.76	0.167
21	1260	237.35	59.7	0.9	0.06	113.93	0.251
22	1320	237.70	62.2	0.8	0.05	95.08	0.209
23	1380	237.00	63.6	0.7	0.06	113.76	0.250
24	1440	236.80	64.8	0.6	0.06	113.66	0.250
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RESULT:

Sediment Removed (lb)	18.21	Sediment Removed per mile (lb)	43.79

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

ICE PIGGING

JOB RECORD/REPORT/SUMMARY

JOB INFORMATION:

Client	NAS Lemoore
Date	9-May-16
Location	Aircraft Pk 1
Insertion Point	C77
Discharge Point	C83
Pipe Length	5100 Lft
Pipe Diameter	8,14
Material	AC
Usage	Domestic Water Distribution
Volume of Ice	2700 Gallons
Ice Fraction	90%
Total Water Used	17107 Gallons

ONSITE PROCEDURE:

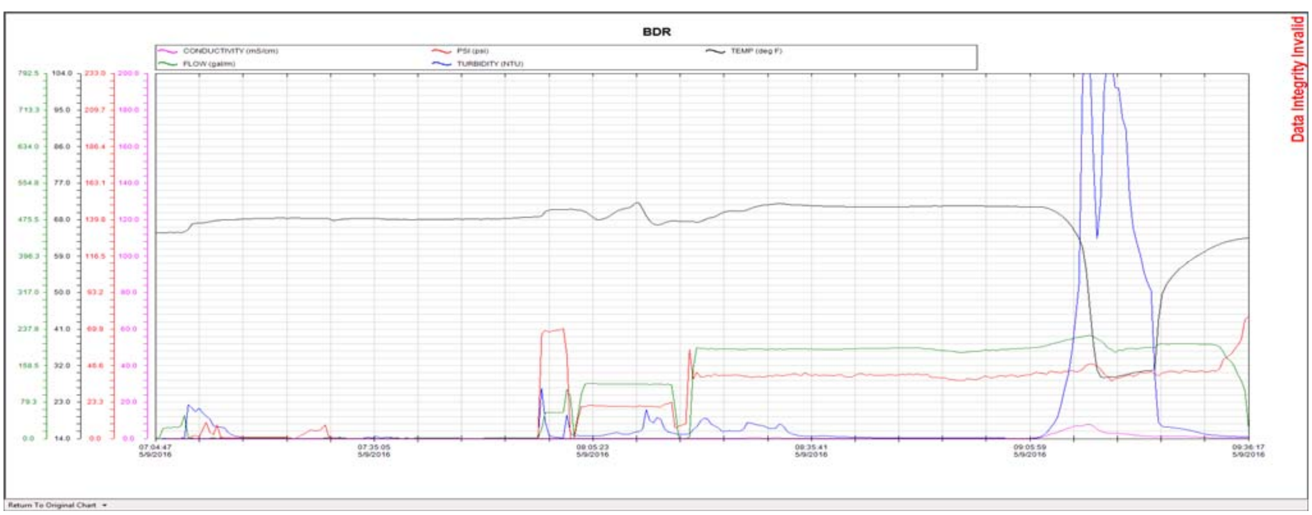
Pre-Clean Readings		Immediate Post-Clean Readings		Change
Turbidity (NTU)	1.5	Turbidity (NTU)	2.1	0.6
Temperature (°F)	68	Temperature (°F)	65	-3
Pressure (PSI)	38	Pressure (PSI)	43	5
Conductivity (mS/cm)	0.2	Conductivity (mS/cm)	0.4	0.2

Timeline:

- Arrive 4:00 AM
- Pre Clean Readings 4:10 AM
- Main Iso by Client 4:28 AM
- Ice In 4:57 AM
- Main Opened 5:18 AM
- Conductivity Alarm 6:10 AM
- Ice Out 6:28 AM
- Post Clean Readings 6:36 AM
- Main Returned to Svc 6:40 AM
- Leave Site 6:45 AM

Comments:

Maximum Flow Rate (gpm)	223	Lowest Temperature Reached (°F)	29.1	Ambient Air Temperature (°F)	72



ICE PIGGING

JOB RECORD/REPORT/SUMMARY

SEDIMENT DATA:

#	Time (s)	Flow Rate (gal/m)	Temperature (°F)	Conductivity (mS/cm)	Sample Mass (g)	Sed. Mass (g/gal/m)	Sedmt (lb/gal/m)
1	60	209.70	69.4	3.9	0.03	50.33	0.111
2	120	214.05	67.9	5.4	0.05	85.62	0.188
3	180	217.70	65.6	6.7	0.08	139.33	0.307
4	240	220.65	62.3	7.1	0.18	317.74	0.699
5	300	223.30	50.8	7.9	0.41	732.42	1.611
6	360	219.00	34.1	6.1	0.45	788.40	1.734
7	420	209.20	29.1	3.8	0.40	669.44	1.473
8	480	195.20	29.3	3.1	0.53	827.65	1.821
9	540	190.10	29.3	3.1	0.25	380.20	0.836
10	600	192.10	29.5	2.8	0.46	706.93	1.555
11	660	195.35	29.9	2.4	0.12	187.54	0.413
12	720	195.15	30.3	2.0	0.09	140.51	0.309
13	780	197.10	30.6	1.6	0.10	157.68	0.347
14	840	198.35	30.8	1.4	0.10	158.68	0.349
15	900	201.30	37.1	1.2	0.12	193.25	0.425
16	960	205.60	50.6	1.3	0.09	148.03	0.326
17	1020	205.60	53.6	1.3	0.08	131.58	0.289
18	1080	206.00	55.6	1.3	0.08	131.84	0.290
19	1140	206.35	57.1	1.3	0.07	115.56	0.254
20	1200	205.65	58.4	1.1	0.04	65.81	0.145
21	1260	205.25	59.5	0.9	0.03	49.26	0.108
22	1320	204.50	60.5	0.7	0.03	49.08	0.108
23	1380	203.70	61.4	0.6	0.03	48.89	0.108
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RESULT:

Sediment Removed (lb)	13.81	Sediment Removed per mile (lb)	14.32

The above values are calculated from samples taken every 60 seconds on site. For each sample the flow rate, and the sediment densities are assumed to remain constant within that 60 second period. From this we can calculate the total amount of water/ice and therefore can estimate the total mass of sediment over the sampling period

Appendix E: Plots of Sediment Removal by Ice Pigging

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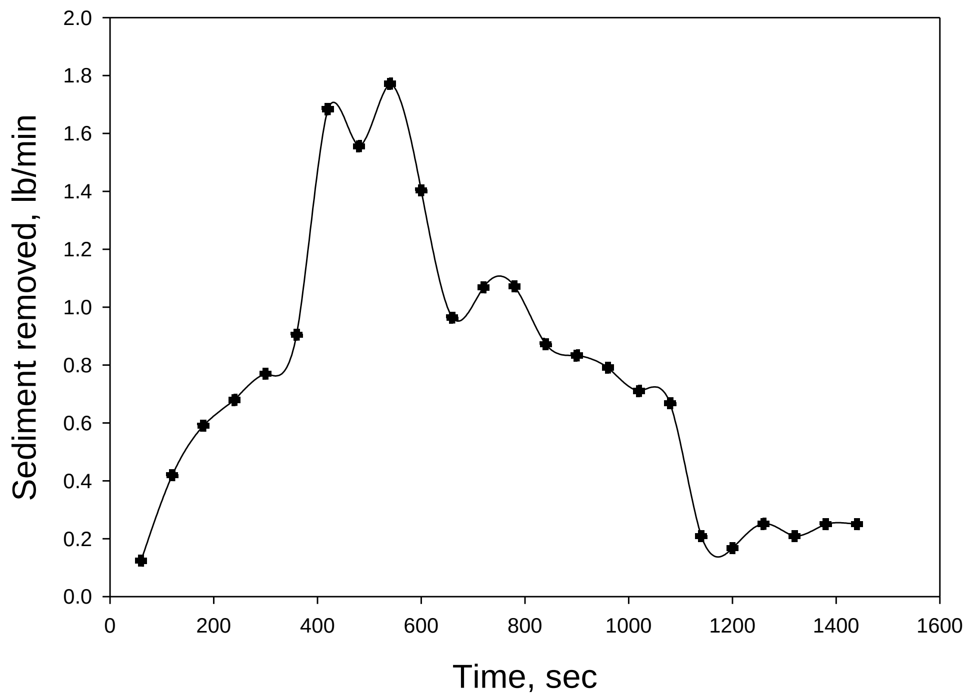

Figure E1. Sediment removed at Hangar 2

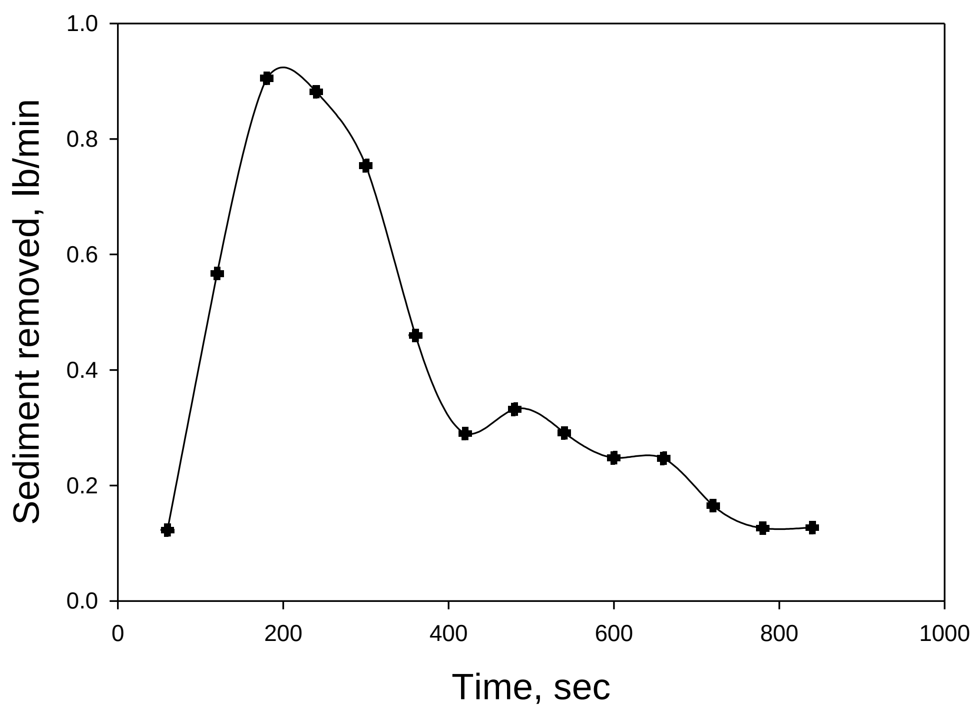

Figure E2. Sediment removed at Ordnance Road

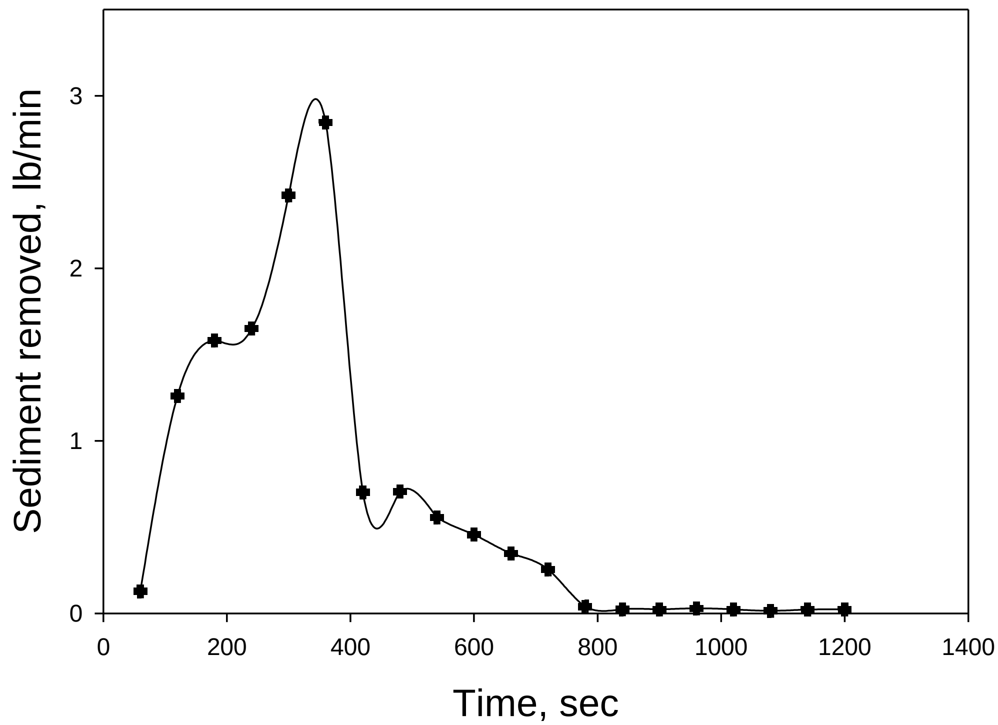

Figure E3. Sediment removed at Ordnance Road Circle

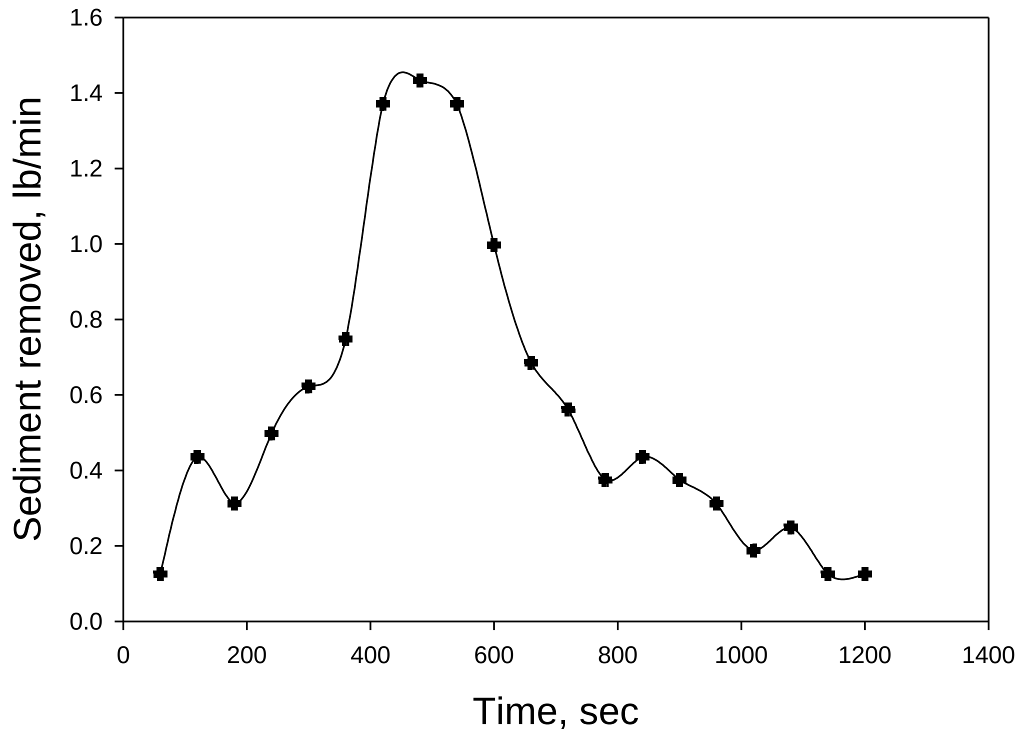

Figure E4. Sediment removed at Reeves

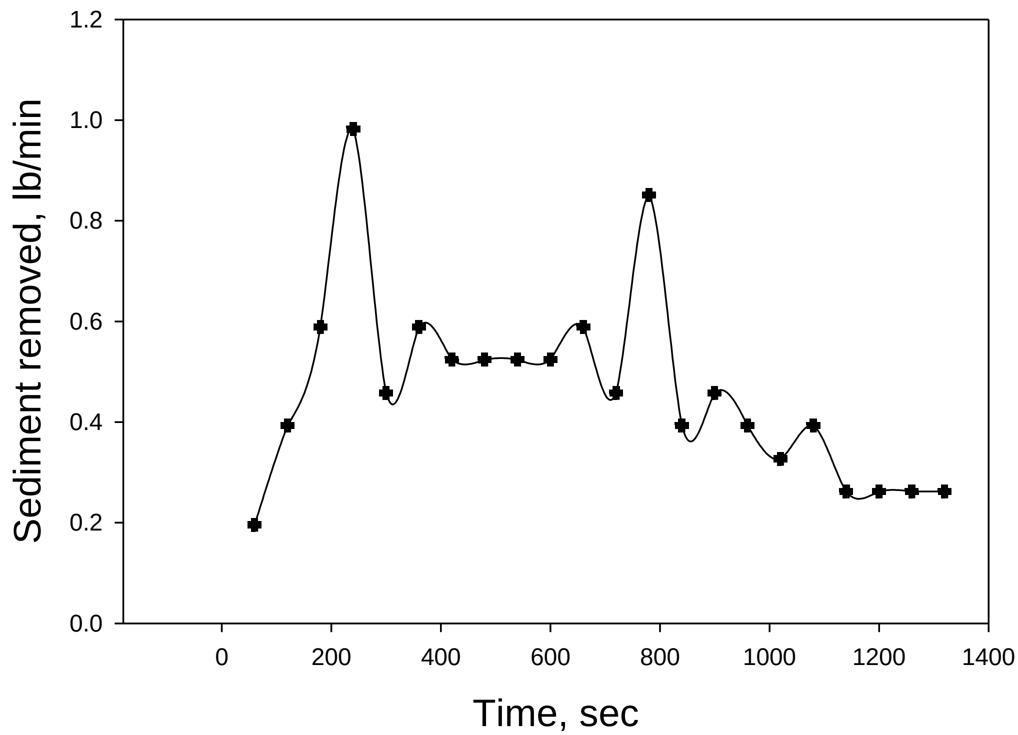

Figure E5. Sediment removed at Suspect Cargo

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Appendix F: Cost Analysis Input and Output Data

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NIST BLCC 5.3-09: Input Data Listing

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Users\faquang\Documents\BLCC5\IcePigging-Jan2018-rev1.xml
Date of Study:	Thu May 03 23:07:27 GMT 2018
Analysis Type:	Federal Analysis, Financed Project
Project Name:	Ice Pigging
Project Location:	California
Analyst:	SF
Base Date:	October 1, 2017
Study Period:	7 years 0 months (October 1, 2017 through September 30, 2024)
Discount Rate:	2.4%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are NOMINAL (inclusive of general inflation)

Alternative: Ice Pigging

Water: IP Water Costs

	Annual Usage		Annual Disposal	
	Units/Year	**Price/Unit**	**Units/Year**	**Price/Unit**
@Summer Rates	1,168,350.0 L	$0.00400	0.0 L	$0.00000
@Winter Rates	1,168,350.0 L	$0.00400	0.0 L	$0.00000

Escalation Rates - Usage

From Date	Duration	Usage Cost Escalation
October 1, 2017	**Remaining**	1.2%

Escalation Rates - Disposal

From Date	Duration	Disposal Cost Escalation
October 1, 2017	Remaining	1.2%

Usage Indices - Usage

From Date	Duration	Index
October 1, 2017	Remaining	100%

Usage Indices - Disposal

From Date	Duration	Index
October 1, 2017	Remaining	100%

Component:

Initial Investment

Initial Cost Paid By Agency (base-year $):	$194,979
Initial Cost Financed (base-year $):	$194,979
Annual Rate of Increase:	1.2%
Expected Asset Life:	7 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 1.2%

Years/Months (from Date)	Date	Portion
0 years 0 months	October 1, 2017	100%

Recurring OM&R: Hydrant Flushing O&M

Amount: $1,173

Annual Rate of Increase:	1.2%

Usage Indices

From Date	Duration	Factor
October 1, 2017	**Remaining**	100%

Recurring OM&R: Flusher Replacement

Amount:	$568
Annual Rate of Increase:	1.2%

Usage Indices

From Date	Duration	Factor
October 1, 2017	**Remaining**	100%

Non-Recurring OM&R: IP Operational Support

Years/Months:	0 years 0 months
Amount:	$13,200
Annual Rate of Increase:	0%

Alternative: BaseCase

Water: Water Cost

	Annual Usage		Annual Disposal	
	Units/Year	**Price/Unit**	**Units/Year**	**Price/Unit**
@Summer Rates	2,750,800.0 L	$0.00400	0.0 L	$0.00000
@Winter Rates	2,750,800.0 L	$0.00400	0.0 L	$0.00000

Escalation Rates - Usage

From Date	Duration	Usage Cost Escalation
October 1, 2017	Remaining	1.2%

Escalation Rates - Disposal

From Date	Duration	Disposal Cost Escalation
October 1, 2017	Remaining	1.2%

Usage Indices - Usage

From Date	Duration	Index
October 1, 2017	Remaining	100%

Usage Indices - Disposal

From Date	Duration	Index
October 1, 2017	Remaining	100%

Component:

Initial Investment

Initial Cost Paid By Agency (base-year $):	$15,000
Initial Cost Financed (base-year $):	$15,000
Annual Rate of Increase:	1.2%
Expected Asset Life:	10 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 1.2%

Years/Months (from Date)	Date	Portion
0 years 0 months	October 1, 2017	100%

Recurring OM&R: Chlorine Costs

Amount:	$469
Annual Rate of Increase:	1.2%

Usage Indices

From Date	Duration	Factor
October 1, 2017	**Remaining**	100%

Recurring OM&R: Flushing Costs

Amount:	$3,520
Annual Rate of Increase:	1.2%

Usage Indices

From Date	Duration	Factor
October 1, 2017	**Remaining**	100%

Recurring OM&R: Flushers Replacement

Amount:	$1,705
Annual Rate of Increase:	1.2%

Usage Indices

From Date	Duration	Factor
October 1, 2017	**Remaining**	100%

NIST BLCC 5.3-09: Detailed LCC Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Users\faquang\Documents\BLCC5\IcePigging-Jan2018-rev1.xml
Date of Study:	Thu May 03 23:08:17 GMT 2018
Analysis Type:	Federal Analysis, Financed Project
Project Name:	Ice Pigging
Project Location:	California
Analyst:	SF
Base Date:	October 1, 2017
Study Period:	7 years 0 months (October 1, 2017 through September 30, 2024)
Discount Rate:	2.4%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are NOMINAL (inclusive of general inflation)

Alternative: Ice Pigging

Initial Cost Data (not Discounted)

Initial Capital Costs Paid By Agency

(adjusted for price escalation)

Initial Capital Costs for All Components: $194,979

Component:

Cost-Phasing

Date	Portion	Yearly Cost
October 1, 2017	100%	$194,979

	------------	------------
Total (for Component)		$194,979

Initial Capital Costs Financed

(base-year dollars)

Initial Capital Costs for All Components: $194,979

Component:

Initial Cost Financed $194,979

Water Costs: IP Water Costs

(base-year dollars)

	Average Annual Usage		Average Annual Disposal		Average Annual
Water	**Units/Year**	**Price/Unit**	**Units/Year**	**Price/Unit**	**Cost**
@ Summer Rates	1,168,350.0 L	$0.00400	0.0 L	$0.00000	$4,673
@ Winter Rates	1,168,350.0 L	$0.00400	0.0 L	$0.00000	$4,673

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs Paid By Agency	$194,979	$30,600
Contract-Related Costs		
Annually Recurring Contract Costs	$0	$0
Non-Annually Recurring Contract Costs	$0	$0
	------------	------------
Subtotal (for Contract):	$0	$0
Energy Costs		

Energy Consumption Costs	$0	$0
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$0	$0
Water Usage Costs	$62,434	$9,798
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$11,629	$1,825
Non-Annually Recurring Costs	$13,200	$2,072
	------------	------------
Subtotal (for OM&R):	$24,829	$3,897
Replacements to Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$282,243	$44,295

Emissions Summary

Energy Name	**Annual**	**Life-Cycle**
Total:		

CO2	0.00 kg	0.00 kg
SO2	0.00 kg	0.00 kg
NOx	0.00 kg	0.00 kg

Alternative: BaseCase

Initial Cost Data (not Discounted)

Initial Capital Costs Paid By Agency

(adjusted for price escalation)

Initial Capital Costs for All Components: $15,000

Component:

Cost-Phasing

Date	Portion	Yearly Cost
October 1, 2017	100%	$15,000
	------------	------------
Total (for Component)		$15,000

Initial Capital Costs Financed

(base-year dollars)

Initial Capital Costs for All Components: $15,000

Component:

Initial Cost Financed $15,000

Water Costs: Water Cost

(base-year dollars)

Water	Average Annual Usage Units/Year	Price/Unit	Average Annual Disposal Units/Year	Price/Unit	Average Annual Cost
@ Summer Rates	2,750,800.0 L	$0.00400	0.0 L	$0.00000	$11,003
@ Winter Rates	2,750,800.0 L	$0.00400	0.0 L	$0.00000	$11,003

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs Paid By Agency	$15,000	$2,354
Contract-Related Costs		
Annually Recurring Contract Costs	$0	$0
Non-Annually Recurring Contract Costs	$0	$0
	------------	------------
Subtotal (for Contract):	$0	$0
Energy Costs		
Energy Consumption Costs	$0	$0
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$0	$0
Water Usage Costs	$146,997	$23,069
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$38,034	$5,969
Non-Annually Recurring Costs	$0	$0
	------------	------------
Subtotal (for OM&R):	$38,034	$5,969
Replacements to Capital Components		

Component:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$200,031	$31,392

Emissions Summary

Energy Name	Annual	Life-Cycle
Total:		
CO2	0.00 kg	0.00 kg
SO2	0.00 kg	0.00 kg
NOx	0.00 kg	0.00 kg

NIST BLCC 5.3-09: Summary LCC

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Users\faquang\Documents\BLCC5\IcePigging-Jan2018-rev1.xml
Date of Study:	Thu May 03 23:09:04 GMT 2018
Analysis Type:	Federal Analysis, Financed Project
Project Name:	Ice Pigging
Project Location:	California
Analyst:	SF
Base Date:	October 1, 2017
Study Period:	7 years 0 months (October 1, 2017 through September 30, 2024)
Discount Rate:	2.4%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are NOMINAL (inclusive of general inflation)

Alternative: Ice Pigging

LCC Summary

	Present Value	Annual Value
Initial Cost Paid By Agency	$194,979	$30,600
Annually Recurring Contract Costs	$0	$0
Non-Annually Recurring Contract Costs	$0	$0
Energy Consumption Costs	$0	$0
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$62,434	$9,798
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$11,629	$1,825

Non-Annually Recurring OM&R Costs	$13,200	$2,072
Replacement Costs	$0	$0
Less Remaining Value	$0	$0
	------------	------------
Total Life-Cycle Cost	$282,243	$44,295

Alternative: BaseCase

LCC Summary

	Present Value	Annual Value
Initial Cost Paid By Agency	$15,000	$2,354
Annually Recurring Contract Costs	$0	$0
Non-Annually Recurring Contract Costs	$0	$0
Energy Consumption Costs	$0	$0
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$146,997	$23,069
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$38,034	$5,969
Non-Annually Recurring OM&R Costs	$0	$0
Replacement Costs	$0	$0
Less Remaining Value	$0	$0
	------------	------------
Total Life-Cycle Cost	$200,031	$31,392

NIST BLCC 5.3-09: Comparative Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: BaseCase

Alternative: Ice Pigging

General Information

File Name:	C:\Users\faquang\Documents\BLCC5\IcePigging-Jan2018-rev1.xml
Date of Study:	Thu May 03 23:09:54 GMT 2018
Project Name:	Ice Pigging
Project Location:	California
Analysis Type:	Federal Analysis, Financed Project
Analyst:	SF
Base Date:	October 1, 2017
Study Period:	7 years 0 months(October 1, 2017 through September 30, 2024)
Discount Rate:	2.4%
Discounting Convention:	End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs Paid By Agency:			
Capital Requirements as of Base Date	$15,000	$194,979	-$179,979
Future Costs:			
Recurring and Non-Recurring Contract Costs	$0	$0	$0
Energy Consumption Costs	$0	$0	$0

Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$146,997	$62,434	$84,563
Recurring and Non-Recurring OM&R Costs	$38,034	$24,829	$13,204
Capital Replacements	$0	$0	$0
Residual Value at End of Study Period	$0	$0	$0
	------------	------------	------------
Subtotal (for Future Cost Items)	$185,031	$87,264	$97,767
	------------	------------	------------
Total PV Life-Cycle Cost	$200,031	$282,243	-$82,212

Net Savings from Alternative Compared with Base Case

PV of Operational Savings	$97,767
- PV of Differential Costs	$179,979

Net Savings	-$82,212

NOTE: Meaningful SIR, AIRR and Payback can not be computed for Financed Projects.

Comparison of Contract Payments and Savings from Alternative

(undiscounted)

Year Beginning	**Savings in Contract Costs**	**Savings in Energy Costs**	**Savings in Total Operational Costs**	**Savings in Total Costs**
Oct 2017	$0	$0	$3,611	-$176,368
Oct 2018	$0	$0	$17,013	$17,013
Oct 2019	$0	$0	$17,217	$17,217
Oct 2020	$0	$0	$17,424	$17,424
Oct 2021	$0	$0	$17,633	$17,633
Oct 2022	$0	$0	$17,844	$17,844

Oct 2023	$0	$0		$18,058	$18,058

NIST BLCC 5.3-09: Detailed LCC Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Users\faquang\Documents\BLCC5\IcePigging-Jan2018-rev1-2.xml
Date of Study:	Thu May 03 23:14:55 GMT 2018
Analysis Type:	Federal Analysis, Financed Project
Project Name:	Ice Pigging
Project Location:	California
Analyst:	SF
Base Date:	October 1, 2017
Study Period:	7 years 0 months (October 1, 2017 through September 30, 2024)
Discount Rate:	2.4%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are NOMINAL (inclusive of general inflation)

Alternative: Ice Pigging

Initial Cost Data (not Discounted)

Initial Capital Costs Paid By Agency

(adjusted for price escalation)

Initial Capital Costs for All Components: $194,979

Component:

Cost-Phasing

Date	Portion	Yearly Cost
October 1, 2017	100%	$194,979

	------------	------------
Total (for Component)		$194,979

Initial Capital Costs Financed

(base-year dollars)

Initial Capital Costs for All Components: $194,979

Component:

Initial Cost Financed $194,979

Water Costs: IP Water Costs

(base-year dollars)

	Average Annual Usage		Average Annual Disposal		Average Annual
Water	**Units/Year**	**Price/Unit**	**Units/Year**	**Price/Unit**	**Cost**
@ Summer Rates	1,168,350.0 L	$0.00800	0.0 L	$0.00000	$9,347
@ Winter Rates	1,168,350.0 L	$0.00800	0.0 L	$0.00000	$9,347

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs Paid By Agency	$194,979	$30,600
Contract-Related Costs		
Annually Recurring Contract Costs	$0	$0
Non-Annually Recurring Contract Costs	$0	$0
	------------	------------
Subtotal (for Contract):	$0	$0
Energy Costs		

Energy Consumption Costs	$0	$0
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$0	$0
Water Usage Costs	$124,868	$19,597
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$11,629	$1,825
Non-Annually Recurring Costs	$13,200	$2,072
	------------	------------
Subtotal (for OM&R):	$24,829	$3,897
Replacements to Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$344,677	$54,093

Emissions Summary

Energy Name Annual Life-Cycle

Total:

CO_2	0.00 kg	0.00 kg
SO_2	0.00 kg	0.00 kg
NOx	0.00 kg	0.00 kg

Alternative: BaseCase

Initial Cost Data (not Discounted)

Initial Capital Costs Paid By Agency

(adjusted for price escalation)

Initial Capital Costs for All Components: $15,000

Component:

Cost-Phasing

Date	Portion	Yearly Cost
October 1, 2017	100%	$15,000
	------------	------------
Total (for Component)		$15,000

Initial Capital Costs Financed

(base-year dollars)

Initial Capital Costs for All Components: $15,000

Component:

Initial Cost Financed $15,000

Water Costs: Water Cost

(base-year dollars)

	Average Annual Usage		Average Annual Disposal		Average Annual
Water	Units/Year	Price/Unit	Units/Year	Price/Unit	Cost
@ Summer Rates	2,750,800.0 L	$0.00800	0.0 L	$0.00000	$22,006
@ Winter Rates	2,750,800.0 L	$0.00800	0.0 L	$0.00000	$22,006

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs Paid By Agency	$15,000	$2,354
Contract-Related Costs		
Annually Recurring Contract Costs	$0	$0
Non-Annually Recurring Contract Costs	$0	$0
	------------	------------
Subtotal (for Contract):	$0	$0
Energy Costs		
Energy Consumption Costs	$0	$0
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$0	$0
Water Usage Costs	$293,994	$46,139
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$38,034	$5,969
Non-Annually Recurring Costs	$0	$0
	------------	------------
Subtotal (for OM&R):	$38,034	$5,969
Replacements to Capital Components		

Component:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$347,027	$54,462

Emissions Summary

Energy Name	Annual	Life-Cycle
Total:		
CO_2	0.00 kg	0.00 kg
SO_2	0.00 kg	0.00 kg
NO_x	0.00 kg	0.00 kg

NIST BLCC 5.3-09: Comparative Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: BaseCase

Alternative: Ice Pigging

General Information

File Name:	C:\Users\faquang\Documents\BLCC5\IcePigging-Jan2018-rev1-2.xml
Date of Study:	Thu May 03 23:13:50 GMT 2018
Project Name:	Ice Pigging
Project Location:	California
Analysis Type:	Federal Analysis, Financed Project
Analyst:	SF
Base Date:	October 1, 2017
Study Period:	7 years 0 months(October 1, 2017 through September 30, 2024)
Discount Rate:	2.4%
Discounting Convention:	End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs Paid By Agency:			
Capital Requirements as of Base Date	$15,000	$194,979	-$179,979
Future Costs:			
Recurring and Non-Recurring Contract Costs	$0	$0	$0
Energy Consumption Costs	$0	$0	$0

Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$293,994	$124,868	$169,125
Recurring and Non-Recurring OM&R Costs	$38,034	$24,829	$13,204
Capital Replacements	$0	$0	$0
Residual Value at End of Study Period	$0	$0	$0
	------------	------------	------------
Subtotal (for Future Cost Items)	$332,027	$149,698	$182,330
	------------	------------	------------
Total PV Life-Cycle Cost	$347,027	$344,677	$2,351

Net Savings from Alternative Compared with Base Case

PV of Operational Savings	$182,330
- PV of Differential Costs	$179,979

Net Savings	$2,351

NOTE: Meaningful SIR, AIRR and Payback can not be computed for Financed Projects.

Comparison of Contract Payments and Savings from Alternative

(undiscounted)

Year Beginning	**Savings in Contract Costs**	**Savings in Energy Costs**	**Savings in Total Operational Costs**	**Savings in Total Costs**
Oct 2017	$0	$0	$16,422	-$163,557
Oct 2018	$0	$0	$29,977	$29,977
Oct 2019	$0	$0	$30,338	$30,338
Oct 2020	$0	$0	$30,702	$30,702
Oct 2021	$0	$0	$31,070	$31,070
Oct 2022	$0	$0	$31,442	$31,442

Oct 2023	$0	$0		$31,819	$31,819